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NAVAL ELECTRICIANS' TEXT BOOK

—BULLARD

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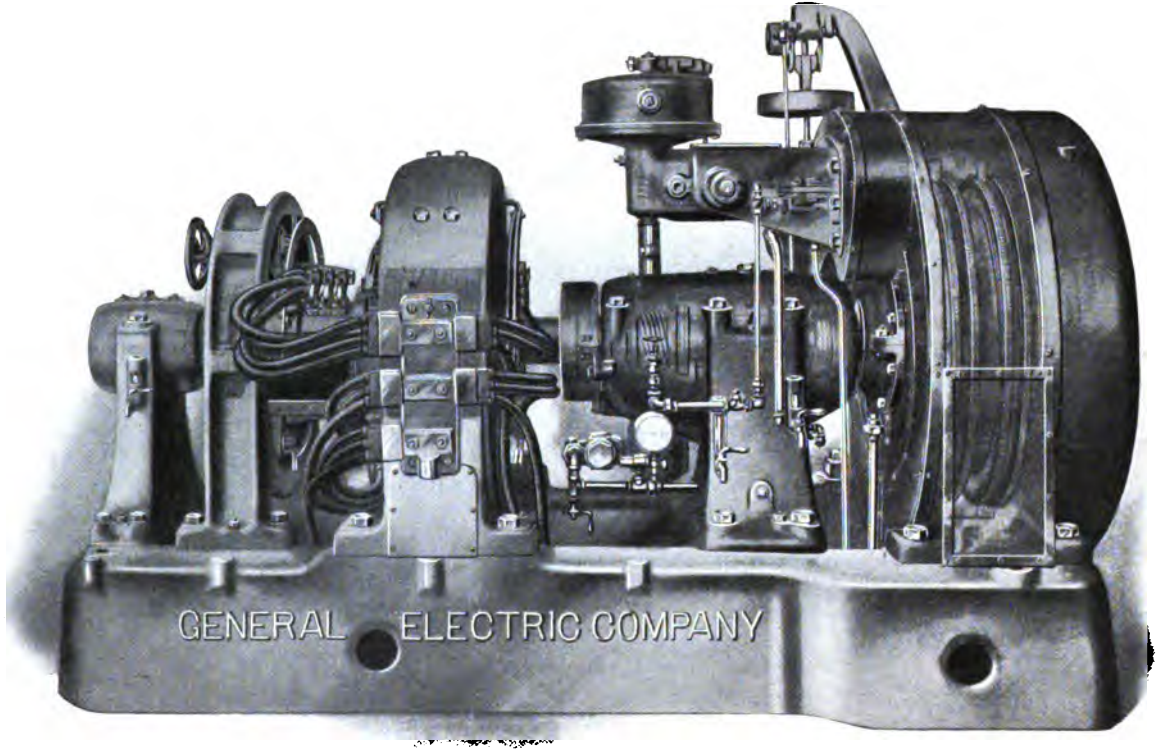

PHANTOM VIEW OF CURTIS STEAM TURBINE DIRECT CONNECTED TO 100 KW. DIRECT CURRENT GENERATOR.

NAVAL ELECTRICIANS' TEXT BOOK

BY

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PREFACE

This book is a revised and enlarged edition of the Naval Electricians' Text and Hand Book. Many new chapters have been added to the original manuscript and all have been more or less rewritten and to such an extent that it has lost its hand-book characteristics. As stated in the first edition, there is probably little or nothing contained in it that cannot be found elsewhere, but an attempt has been made to collect complete information concerning the principles and uses of electricity as applied to our ships of war.

It is primarily intended for use as a text book by midshipmen at the Naval Academy, but officers and the enlisted personnel and electricians should find it a fairly complete treatise on electricity as far as it relates to the subject of our warship installation.

It would be difficult to give credit to all those who have made suggestions for improvement of the book but special mention should be made of the officials of the General Electric Company who have contributed many illustrations of the appliances made by them and furnished much valuable manuscript. Due credit has been given to other manufacturers and to those who have allowed the results of their experiments to be used.

W. H. G. BULLARD,
Lieut.-Commander U. S. Navy.

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CHAPTER I.

DERIVATION AND DEFINITION OF UNITS.

All units used in the science of electricity are based on the units of the metric system, a system in which certain standards are adopted for measuring the three fundamental quantities of **length, mass** and **time.**

Standards of the Metric System.

Length.—The unit of length in the metric system is a **metre,** and was originally intended to be the one ten-millionth part of the distance from the earth's equator to the pole measured over the surface of the earth along the meridian passing through Paris. The present standard of length is the metre, and is the distance at 0° C. between the ends of a platinum rod preserved in the Archives of the French Capital. This distance is slightly less than the original measured distance, as the earth's quadrant is now found to measure 10,000,880 metres.

Each metre is equal to 10 decimetres, or

100 centimetres, or
1000 millimetres,

and 1000 metres make a kilometre.

A metre is 39.37043 inches, or 3.28 feet.

A decimetre is very nearly 4 inches (3.937 inches).

A millimetre is very nearly equal to $\frac{1}{25}$ of an inch.

The kilometre is about $\frac{5}{8}$ of a mile, or 1093.6 yards.

Mass.—The unit of mass is the kilogramme, and is equal to the weight of the standard kilogramme, a piece of platinum preserved with the standard metre in the Archives at Paris. It is intended to have the same weight as a cubic decimetre of water at its temperature of maximum density, 3.9° C.

The kilogramme is about 2.2 pounds.

Time.—The unit of time is the **second**, and is the $\frac{1}{86400}$th part of a mean solar day.

C. G. S. (Centimetre, Gramme, Second) System.

In the C. G. S. system, the **centimetre**, $\frac{1}{100}$ th part of a metre is taken as the unit of length; the **gramme**, $\frac{1}{1000}$th part of a kilogramme is taken as the unit of mass and the **second** is taken as the unit of time.

Derived Mechanical Units of the C. G. S. System.—There are certain mechanical units derived from the three fundamental units, such as *area, volume, velocity, acceleration, force, work, power*, and *heat*. Mechanical and electrical quantities are closely related, and in order that the definitions of the electrical units may be understood, it is first necessary to consider the mechanical units.

Area.—The unit of area is the square of the unit of length, or *square centimetre.*

Volume.—The unit of volume is the cube of the unit of length, or *cubic centimetre.*

Velocity.—The unit of velocity is the velocity of a body that moves through unit length in unit time, or it is a velocity of *one centimetre per second.* It is called the **kine.**

Acceleration.—The unit of acceleration is the acceleration which gives unit velocity in unit time, or an acceleration of *one centimetre per second in one second.* It is called the **spoud.**

Acceleration is the rate of change of velocity. If at a certain instant a moving body has a velocity V, and at the end of a given interval T, it has a velocity V', its change of velocity has been $V' - V$, and the acceleration or rate of change of velocity is

$$A = \frac{V' - V}{T}.$$

One of the most common examples of acceleration is that due to the attraction of the earth, and bodies falling freely under the action of gravity have an acceleration of 32.2 feet per second. This means that at the end of each second, its velocity is 32.2 feet per second greater than the velocity at the beginning of the second.

A body falling from rest will fall 16.1 feet in the first second, as its acceleration is 32.2 feet, which is its velocity at the end of the second, since $V = AT$ and $T = 1$. The average velocity then is

$$V = \frac{0 + 32.2}{2} = 16.1 \text{ feet},$$

and the distance fallen is the time multiplied by the average velocity, or

$$L = VT = 16.1 \times 1 = 16.1 \text{ feet}.$$

At the end of the second second, its velocity has been increased by 32.2 feet, or it is now $32.2 + 32.2 = 64.4$ feet, and the average velocity in the second second is

$$V = \frac{32.2 + 64.4}{2} = 48.3 \text{ feet},$$

and the distance fallen in the second second is

$$L = VT = 48.3 \text{ feet}.$$

At the end of the third second, its velocity has been increased by 32.2 feet, or it is now $64.4 + 32.2 = 96.6$ feet, and the average velocity in the third second is

$$V = \frac{64.4 + 96.6}{2} = 80.5 \text{ feet},$$

and the distance fallen in the third second is

$$L = VT = 80.5, \text{ etc.}$$

The total distance fallen in three seconds is

$$16.1 + 48.3 + 80.5 = 144.9 \text{ feet}.$$

This is also derived as follows:

$$V' - V = AT \text{ and } L = \left(\frac{V'' + V}{2}\right)T,$$

or

$$L = VT + \tfrac{1}{2}AT^2$$

in starting from rest $V = 0$, or

$$L = \tfrac{1}{2}AT^2,$$

and in the case above

$$L = \tfrac{1}{2} \times 32.2 \times 3^2 = 144.9 \text{ feet}.$$

Examples of Acceleration.

1. A body travels at the rate of 12 feet per second; in 10 seconds it is moving at the rate of 7 seconds per second; what is the mean acceleration? *Ans.* ½ ft. per sec.

2. A body moves in the first second through a space of 16 feet and in the fourth second through 112 feet, what is the acceleration per second? and how far does it move in the second second and the third second?

Ans. 32 feet per sec.
48 feet 2d sec.
80 feet 3d sec.

Force.—The unit of force is that force which acting for one second on a free gramme mass, will impart to it a velocity of one centimetre per second. The unit of force is called the **dyne.**

Force is an attribute of matter that produces or tends to produce motion or change of motion. Whenever force moves a mass, it imparts to it a certain velocity, and if it moves a unit mass with a velocity of one centimetre per second in one second it will produce unit acceleration and force and mass are thus connected by the formula

$$F = MA$$

the fundamental equation of force.

There are many kinds of force, such as mechanical, physical, electrical, gravitational, etc. It has already been shown how the earth's attraction, or force of gravity, acts to produce acceleration, and the force with which any body is held to the earth is the product of its mass and the acceleration due to the force of gravity. Thus a kilogramme mass is attracted to the earth with a force of

$$1000 \times 981 = 981{,}000 \text{ dynes.}$$

The acceleration of gravity is 32.2 feet per second, or since 1 foot $= \frac{100}{3.28}$ centimetres, it is

$$\frac{32.2 \times 100}{3.28} = 981 \text{ centimetres per second;}$$

and since $F = MA$, the force on one gramme is

$$F = 1 \times 981 = 981 \text{ dynes.}$$

The unit of force in the English system of units is defined to be that force that, if applied to a pound mass for one second, produces a velocity of one foot per second. It is called the **poundal.**

The force exerted by gravity produces a velocity of 32.2 feet per second, and therefore the force exerted on one pound by the force of gravity is

$$F = MA = 1 \times 32.2 = 32.2 \text{ poundals.}$$

Mass is the quantity of matter in a body and **weight** is a measure of the attraction of gravity on the body; thus the weight of one gramme is

$$F = MA = 1 \times 981 = 981 \text{ dynes.}$$

Examples of Force.

1. A constant force acting upon a mass of 30 grammes causes it to move through 10 metres in 3 secs. starting from rest. What is the value of the force in dynes? *Ans.* 6,666⅔ dynes.

2. Express the weight of 10 kilos. in dynes, and the value of a dyne in terms of a grammes weight. $g = 981$ dynes. *Ans.* 9,810,000 dynes. $\frac{1}{981}$ grm.

3. A spring balance is carried in a balloon which is ascending vertically. What is the acceleration of the balloon when an 8-oz. weight hung upon the spring balance is found to indicate 9 oz.? $g = 32$. *Ans.* 4 ft. per sec.

4. A body of mass 4 pounds is moving at the rate of 8 feet per second. At this instant a constant force begins to act upon it in the direction of its motion, and after 20 seconds, its velocity has increased to 24 feet per second. Determine the magnitude of the force. *Ans.* 3.2 poundals.

Work.—The unit of work is the work done in overcoming unit force in unit distance, or the work done in overcoming one dyne in one centimetre, or the work done by one dyne working through one centimetre. It is called the **erg.**

Work is done on a body when a force causes it to move or to change its direction of motion. A body does work when it overcomes another force in a certain distance. Thus a locomotive drawing a train of cars does work against the friction of the rails,

resistance of the air, etc. If the force producing the work is removed, if steam is cut off, the train will be brought to rest in a certain distance by the force due to the resistances that were previously overcome. It is necessary to produce motion in some direction for work to be done, however great a force may be applied. A locomotive may exert considerable force but unless the train or itself is moved, it does no work.

The English absolute unit of work is the foot-poundal, and is the work done by a force of one poundal acting through a distance of one foot.

The practical unit is the foot-pound, which is the work done in raising one pound one foot against gravity. Since $F = MA$, the force overcome in raising one pound is $F = 1 \times 32.2$ poundals, and the work done is

$$W = FL = 32.2 \times 1 = 32.2 \text{ foot-poundals.}$$

Therefore, one foot-pound = 32.2 foot-poundals.

Energy.—Energy is the power of doing work. A body may have the power to do work, but yet restrained from doing it. Thus a body held at a given distance from the earth's surface has the power of doing work and can do so if the restraining force holding it is removed. It may fall and do work, as in the case of the hammer of a pile-driver. This energy due to its position is called **potential energy.**

The measure of its potential energy is the amount of work expended in putting it in position. Thus, to raise a certain mass M to a certain height L, requires work equal to

$$W = FL, \text{ but } F = MA$$

and

$$W = MAL, \text{ or } PE = MAL,$$

or the body has potential energy equal to MAL.

If the body falls, the potential energy is converted into energy in motion, or **kinetic energy,** and when it reaches the ground from which it was removed, the kinetic energy will be just equal to its potential energy at its highest point and will be again equal to the work required to raise it.

At the moment of striking the ground, it has a velocity V and its kinetic energy at that instant is

$$KE = \tfrac{1}{2} MV^2, \text{ derived as follows:}$$

It has been shown that

$$L = \tfrac{1}{2} AT^2 \text{ and } V = AT.$$

Therefore,

$$PE = MAL = M \times \frac{V}{T} \times \tfrac{1}{2} \frac{VT^2}{T} = \tfrac{1}{2} MV^2;$$

and since the potential energy at its highest point is equal to its kinetic energy at its lowest,

$$KE = \tfrac{1}{2} MV^2.$$

Examples of Work and Energy.

1. A body of mass, 3 lbs. is projected vertically upwards with a velocity of 640 feet per second; how much work has been done against gravity when it has ascended to half its maximum height?

Ans. 9600 ft.-lbs.

2. An engine is running at the rate of 80 feet per second on level ground, when steam is shut off. Assuming that the frictional resistances are equivalent to a weight of 14 lbs. per ton, how far will the engine run and for how long? *Ans.* 16,000 feet.
400 secs.

3. A 4-oz. bullet is projected vertically upwards with a velocity of 800 feet per second. What is its potential energy when it has reached its maximum height? *Ans.* 2500 ft.-lbs.

4. A hammer moving at the rate of 12 feet per second hits a nail and drives one inch of its length into a board. The mass of the hammer is half a pound. Assuming it to be inelastic, and to come to rest; find the average resistance it encountered. *Ans.* 432 poundals.

Power.—The unit of power is the *erg per second,* and is the rate of doing work. It is connected with the unit of work by the element of time. Two forces may do the same amount of work in different times, and the one that does it in the shorter time is said to be the more powerful, that is, it can do more work in a given interval of time than the less powerful. If an electric motor can turn a turret once completely around in 10 minutes, and another

motor can turn the same turret once in five minutes, the second one does twice as much work in the same interval of time as the first, and it has therefore twice the power of the first one, though they each do the same amount of actual work; they have overcome the same force in the same distance.

The unit of power in the C. G. S. system has no distinctive name, being called the *unit of activity,* or the erg per second.

The practical unit of power in the English system is the horse-power, equal to work done at the rate of 33,000 foot-pounds per minute, or 550 foot-pounds per second.

The practical unit of power in the C. G. S. system is the **watt,** equal to 44.2 foot-pounds per minute.

Examples of Power.

1. Find the horse power, H. P., of an engine which will in 9 hours empty a vertical shaft of water, whose section is 9 sq. ft. and depth 400 feet. Density of water = 62.5 lbs. per cubic foot. ***Ans.*** **2.525 H. P.**

2. An engine takes a train of 60 tons in all up an incline of 1 in 100 at a maximum speed of 30 miles per hour and it can take a train of 150 tons on the level at the same speed. Find the frictional resistances of the road in lbs. per ton and the rate in H. P. at which the engine works at this speed. ***Ans.*** **14.13 lbs. per ton. 179.16 H. P.**

Heat.—The unit of heat is the amount of heat required to raise the temperature of one gramme of water from 0° to 1° C. It is called the **calorie.**

The work equivalent to one calorie is equal to 42,000,000 ergs.

The British unit of heat is the amount of heat necessary to raise the temperature of one pound of water 1° F.

The relation of these units is given under the unit of electrical work, the joule.

Units in the C. G. S. and Practical Systems.

The underlying principle of these systems of units is the reaction of a magnetic field upon a unit magnetic pole.

A **unit magnetic pole** is one of such strength that it will repel a similar pole with a force of dyne when separated from it one centimetre in air.

A unit magnetic field is one of such strength that a unit magnetic pole placed in it is acted on with a force of one dyne. It is called unit intensity or a **gauss.**

The reaction of a magnetic field upon a unit pole only involves the terms of force and distance, both of which can be accurately measured.

Unit of Current.

An electric current is not a tangible material substance; it cannot be seen; a conductor carrying a current looks to be in the same condition as one in which no current is flowing. It has certain properties; viz., resistance, inductance, and capacity. These depend upon the material, form, and dimensions of the conductors directing the current and upon their relative positions to each other. These properties only become manifest when the circuit is subjected to certain conditions. It will be shown later that electrical resistance is only evident when current is flowing; inductance when current is changing, and capacity when electromotive force is changing.

C. G. S. Unit of Current.—An electric current can only be detected by the effects produced by it. It may produce sound, light or heat, electrolisize certain solutions, or do mechanical work. The mechanical work done is due to the reaction of the current and a magnetic field. The effect produced by a current of electricity on a magnet pole is due, not alone to the current, but in addition (1) to the length of the conductor carrying the current; (2) to the inverse square of the distance of every element of the conductor from the magnet pole; and (3) to the strength of the magnet pole.

In order to find the effect of unit current and to satisfy these conditions, there must be (1) a conductor one unit in length; (2) a conductor every element of which is equally and at unit's distance from the magnet pole; and (3) a magnet pole of unit strength. To connect these units to the C. G. S. system, the current must be directed in a conductor one centimetre long, bent into an arc of a circle one centimetre in radius, at the center of which must be placed a unit magnet pole. Satisfying these last conditions, if a current so strong was made to pass along such a conductor that it

acted on the unit magnet pole with unit force, then that current would be unit current, that is, one electromagnetic unit.

We then arrive at the definition of **unit current** (electromagnetic), as follows: *The unit of current is one of such strength that, if flowing in a conductor one centimetre in length, bent into an arc of a circle one centimetre in radius, it exerts a force of one dyne on a unit magnet pole placed at the point from which the arc is struck.*

A conductor carrying a current and lying in a magnetic field is urged with a certain force across the field, the force being proportional to the length of the conductor and to the strength of the field.

On this consideration, the C. G. S. unit of current exists when *each centimetre of its length is urged across a magnetic field of unit intensity, or one gauss, with a force of one dyne.*

A unit of one-tenth the value of this C. G. S. unit is called the **practical unit of current,** and is the **ampere,** being named for Andre Marie Ampere, a French physicist who lived from 1775 to 1836.

A **milliampere** is a unit one-thousandth of the value of the ampere.

Unit of Quantity of Electricity.

The unit quantity of electricity is that quantity which is conveyed by unit C. G. S. current in one second.

The **practical unit of quantity** is the quantity of electricity conveyed by an ampere in one second. It is equal in value to one-tenth the C. G. S. unit of quantity and is called the **coulomb,** being named for Charles Coloumb, a French mathematician, who lived from 1736 to 1806.

Unit of Electromotive Force (E. M. F.).

If a body is charged with electricity it is said to have a certain potential and is capable of doing work. To charge the body work must be done on it, and this work can be reproduced by allowing the charged body to be connected by a conductor to some other body, when its charge will flow along the conductor and do work. The more work that is done in charging the body the greater is its potential and the more work it is capable of doing.

Difference of Potential.—Difference of potential between two charged bodies is proportional to the difference of work that has been expended in electrifying the bodies. The hammer of a pile-driver that has been raised 20 feet has a certain potential energy. It has the power to do work depending on its height. A certain amount of work has been expended in raising the hammer and this work can be reproduced if it is allowed to fall. A similar hammer that has been raised 10 feet has also a certain potential energy. It has only required half the work to raise it 10 feet as it did to raise the one 20 feet. The difference in the heights of the two hammers represents the difference in the amount of work they can do, and so their potential energies depend on their heights. Similarly, electric potentials may be studied by a consideration of their heights or difference of levels.

The amount of work done in the case of each of the hammers is measured by the height they have been lifted above the earth's surface taken as a common level. So it is convenient to regard electric potentials as being capable of doing work by the degree that they are charged above the potential of the earth, which is regarded as a common level, or zero potential.

Considering as a starting point that the earth is at absolute zero, or neutral potential, a body may be so electrified that it is at a higher potential than the earth, while another may be at a lower potential, depending on the manner they are electrified; or both may be so electrified that they are both higher or both lower than the earth, and yet be at different potentials.

They each have a certain potential and if connected by a conducting medium, an electric current would flow from the one of higher to the one of lower potential, and equilibrium of potential would be established. If the one electrified to a higher potential than the earth be called positive, and it is connected to the earth, there would be a flow of electricity *to* the earth. If the one electrified to a lower potential than the earth be called negative and it is connected to the earth, there would be a flow of electricity *from* the earth. In either case, the potential of the earth would not be changed. The analogy to this is seen in the level of the ocean, which would not be changed if another stream empty into it or a well on land is filled from the ocean.

Electromotive Force.—Difference of potential may be generated in many ways, as by friction, by contact of dissimilar metals, by chemical action, or by magnetic induction. In whatever way produced, the name **electromotive force, E. M. F.,** is given to express the *difference of potential* generated.

If a difference of potential exists between two points, a current will flow from one point to the other, if they are connected by a conducting medium. There will be a gradual *fall* of potential or fall of electric pressure from the one of higher potential to the lower. There is a constant endeavor to equalize the difference of potential and in doing so, electricity flows from one to the other and work is done. If the difference of potential be maintained constant by the continual expenditure of work there will be a constant endeavor to equalization which will result in a continuous flow of current of electricity and continuous electric work.

The constant difference of potential is the total E. M. F. of the circuit, whereas between any two points there is a difference or fall of potential. The sum of all the differences of potential from one point to another around a closed circuit is equal to total fall or total E. M. F.

Fall of potential and total E. M. F. have their analogy in the fall of pressure due to a head of water flowing through restricted pipes.

In Fig. 1 *C* represents a tank filled with water and connected by the column *CB* with a level pipe *AB*, to which are connected vertical pipes *D, E, F, G*. The end of the pipe *A* is fitted with a faucet which may be opened or closed, and *C* is connected to a source of supply so that the level of water in *C* may be kept constant. If at first the faucet at *A* is closed, by a well-known hydrostatic principle, the water will rise in all the pipes until the height in each is on the same level and equal to the height in *C*. The pressure along each portion of *AB* is the same and there is no flow of water. This corresponds to an electric conductor *AB* whose ends are at the same potential; that is, there is the same pressure at each end and, consequently, there is no difference of potential and no movement of electricity.

If now the faucet at *A* is opened and the consequent difference

of water pressure produced between C and A, water will flow in AB and out of each tube, and each level will remain at a height which is determined by the pressure in each tube. If now water is poured into C as fast as it flows out from A, the level of the water in the several tubes will remain stationary, while the flow of water through BA will be constant. Experiment will show that if the cross-section of AB is uniform and the tubes are equally spaced from each other there will be an equal difference in the levels of the tubes, and the fall of pressure may be shown by a straight line connecting the level of the water in C and end of tube A. The

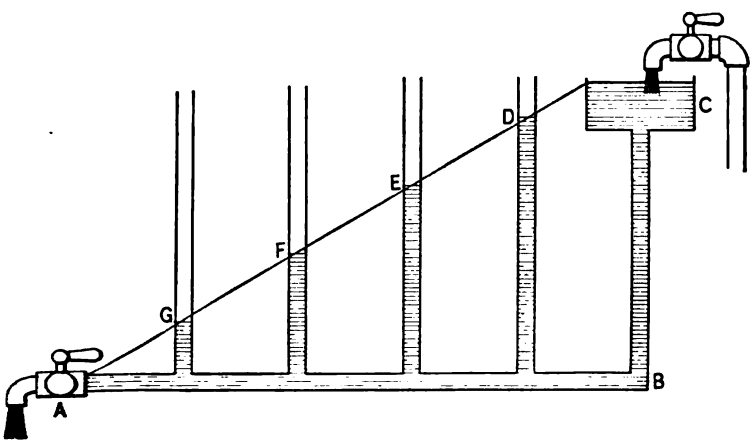


FIG. 1.—Illustrating Fall of Potential.

fall of water pressure is due to the friction of the sides of the pipe BA and the fall of pressure is expended in overcoming this resistance.

This is the case of a conductor whose ends are at different potentials. The level in C represents the total E. M. F. in the circuit and is kept up by the expenditure of work necessary to keep the height of the water at a constant level. In each section of BA there is a drop or fall in potential, and the sum of all the differences from B to A is equal to the total E. M. F., represented by the total head of water. The fall of potential is expended in overcoming the resistance of the conductor, just as the drop in water pressure was expended in overcoming the friction to the pipe.

If the cross-section of AB is not uniform, the water will stand at different heights such that the fall of the pressure between them will not be regular. The different sections will then offer different amounts of friction, so the fall in pressure will be greater or less. And in the case of the electric conductor, if the resistance through any one particular section is great, the fall of potential will be great. However, whatever the area of cross-section, the same amount of water will flow through each section, flowing more rapidly in the smaller sections, and in the electric current, whatever the resistance, the same amount of current flows through each part of the circuit.

C. G. S. Unit of E. M. F.—Of all the means available for generating E. M. F. that by magnetic induction seems the most logical one on which to base a consideration of the definition of the unit E. M. F. and the one which follows most closely the theoretical conditions.

It is an experimental fact that when a conductor is moved across a magnetic field there is produced in it a tendency to set up an induced E. M. F.

A **magnetic field** is a space or region surrounding magnetic substances, either permanent or temporary, in which magnetic force acts; a space filled with so-called *lines of force,* which by their number at any one place represents the quantity or amount of force and by their direction, the resultant direction of the magnetic force.

The C. G. S. unit of electromotive force is defined to be *that E. M. F. produced by the cutting of a magnetic field of one gauss intensity by one centimeter of the conductor moving at a velocity of one centimeter per second.*

A unit one hundred millions times the value of this C. G. S. unit is called the **practical unit of E. M. F.** and is the **volt,** being named for Alessandro Volta, an Italian physicist who lived from 1745 to 1827.

A **millivolt** is a unit one-thousandth of the value of the volt.

Unit of Resistance.

The application of a steady E. M. F. to the ends of a conductor will produce in the conductor a current inversely proportional to

the resistance the conductor offers to the flow of electricity. *A conductor has one electromagnetic unit of resistance when a steady E. M. F. of one electromagnetic unit applied to it produces one electromagnetic unit of current.* This definition is derived from a consideration of Ohm's law.

Ohm's Law.—This law expresses the relation between E. M. F. current and resistance in a closed circuit in which the current is continuous. It states that the current is directly proportional to the E. M. F. and inversely proportional to the resistance, or in symbols,

$$C = \frac{E}{R}$$

where

C = Current,
E = E. M. F.,
R = Resistance.

This relation holds in whatever system of units the quantities are expressed, provided they are all expressed in the same system. This law will be more fully dealt with later, and is only introduced here to help explain the unit of resistance. A consideration of the relation existing between the electromagnetic units of current and E. M. F. and the practical units shows that the ohm must be of a value 1,000,000,000 times as great as the electromagnetic unit of resistance. In both systems of units by Ohm's law

$$C = \frac{E}{R}$$

where C, E, and R represent current, electromotive force, and resistance in the two systems. If C', E', and R' represent the values in the practical system of units and C'', E'', and R'' the values in the electromagnetic system, we have

$$C' = 10^{-1}\, C'',$$
$$E' = 10^{8}\, E'',$$
$$R' = \frac{E'}{C'} \text{ and } R'' = \frac{E''}{C''},$$

whence

$$R' = \frac{10^{8}\, E''}{10^{-1}\, C''} \text{ or } R' = \frac{10^{8}}{10^{-1}} R'' = 10^{9}\, R'';$$

or, in practical units, the ohm, the unit must be 10^9 times as great as the value of the electromagnet unit.

A unit 1,000,000,000 times the value of the C. G. S. unit of resistance is called the **practical unit of resistance** and is the **ohm,** being named for George Simon Ohm, a German mathematician who lived from 1789 to 1854, and who was the first to clearly enunciate Ohm's law.

A **megohm** is a unit one million times as great as the ohm.

A **microhm** is a unit one-millionth of the value of the ohm.

Unit of Power.

The C. G. S. unit of power is defined as the rate at which work is being done when one C. G. S. unit of current works under a pressure of one C. G. S. unit of E. M. F.

The **practical unit of power** has a value ten millions times as great as the C. G. S. unit of power and is called the **watt.**

The watt is defined as the rate at which work is being done when a current of one ampere works under a pressure of one volt and is sometimes referred to as the **volt-ampere.**

To connect the watt with the C. G. S. units of power, it is only necessary to substitute the values of the volt and ampere in terms of the C. G. S. units of electromotive force and current, thus

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

and

$$1 \text{ volt} = 10^8 \text{ C. G. S. units of E. M. F.,}$$
$$1 \text{ ampere} = 10^{-1} \text{ C. G. S. units of current,}$$

or

$$1 \text{ watt} = 10^8 \times 10^{-1} = 10^7 \text{ C. G. S. units of power.}$$

Considering how work in mechanics is defined as the product of a force and the distance moved through due to this force, it is easy to trace the analogy to the derivation of the watt. This is seen in the mechanical work performed by a ventilating fan, the difference of pressure between the entering and leaving orifices forming a current of air, and its power to do work is measured by the difference of pressure produced, and the rate of the moving current of air. The difference of pressure at the orifices corresponds to the

difference of potential of the current, and the air current to the electric current, and their product is the power of the fan, or its rate of doing work. In this connection, it must be recalled that the ampere is not the quantity of current, but rather the rate of flow or quantity in unit time. The total work done in any time would be the number of watts multiplied by the time in seconds.

In order to connect mechanical and electrical units of power, it is sufficient to remember that one mechanical horse-power is equal to 746 watts. This is derived as follows:

$$\begin{aligned} 1 \text{ H. P.} &= 33{,}000 \text{ ft.-lbs. per minute,} \\ &= \quad 550 \text{ ft.-lbs. per second,} \\ 1 \text{ ft.} &= 30.48 \text{ centimetres,} \\ 1 \text{ lb.} &= 453.7 \text{ grammes,} \\ 1 \text{ ft.-lb.} &= 30.48 \times 453.7 = 13{,}828.77 \text{ gramme-centimetres.} \end{aligned}$$

A gramme-centimetre is the work done in raising one unit of mass, one gramme, one centimetre against the force of gravity. The work done must be the product of force overcome and the distance through which it is overcome. The average force of gravity per unit mass of 1 gramme is 981 dynes, and the work done in lifting 1 gramme 1 centimetre against this force is 981 dyne-centimetres. In the derived mechanical units of the C. G. S. system, the dyne-centimetre is called the **erg.** So when 1 gramme is lifted 1 centimetre against gravity, the work done is 981 ergs, or in other words, 1 gramme-centimetre is equal to 981 ergs.

$$\begin{aligned} \therefore \quad 1 \text{ ft.-lb.} &= 13{,}828.77 \times 981 \text{ ergs} \\ &= 13{,}566{,}029 \text{ ergs,} \end{aligned}$$

or

$$1 \text{ H. P.} = 550 \times 13{,}566{,}029 = 7{,}461{,}351{,}900 \text{ ergs per second.}$$

The erg per sec. = the C. G. S. unit of power,

$$\therefore \quad 1 \text{ H. P.} = 746 \times 10^7 \text{ C. G. S. units of power,}$$

$$1 \text{ watt} = 10^7 \text{ C. G. S. units of power,}$$

or

$$1 \text{ H. P.} = 746 \text{ watts.}$$

The watt was named for James Watt, an English physicist, the inventor of the steam engine, who lived from 1736 to 1819.

A unit one thousand times as great as the watt is the **kilowatt.**

To convert			Multiply by	Divide by
Watts	into	H. P.	.00134	746
"	"	ergs per sec.	10^7	
"	"	ft.-lbs. per min.	44.2	
"	"	ft.-lbs. per sec.	.737	
"	"	kilogr.-metres per sec.	.102	9.81
H. P.	"	ft.-lbs. per min.	33.000	
"	"	ft.-lbs. per sec.	550	
"	"	kilowatts	.746	
"	"	watts	746	
"	"	ergs per sec.	7.46×10^9	

Unit of Work.

The C. G. S. unit of work has already been defined. The **practical unit of work** is a unit 10,000,000 times as great as the C. G. S. unit and is called the **joule,** being named for James Prescott Joule, an English physicist, who lived from 1818 to 1889. As heat and work are mutually convertible, it is sometimes referred to as the **electrical unit of heat** and is equal to 10,000,000 ergs. Remembering that the watt is the unit rate of doing work, the number of units of work, or joules, performed in a given time, must be equal to the number of watts multiplied by the number of seconds. The watt was shown to be equal to one volt times one ampere, or

$$W = C \times E,$$

and multiplying by t, we have

$$J = CEt.$$

If $t = 1$ second, the watt is equal to the joule, or the watt may be defined as the work done at the rate of one joule per second. Substituting for E, its value by Ohm's law, $E = CR$,

$$J = C^2Rt.$$

When C, R, and t are all unity, J is unity, and remembering that the joule is the unit of work, expressed as heat, it may be defined *as the heat developed in a conductor in one second by a current of one ampere flowing through a resistance of one ohm.*

The mechanical work equal to one heat unit in the English system of units, for 1° F. is taken to be 778 ft.-lbs., this number being determined by experiment. This means that 778 ft.-lbs. of work, if converted into heat, would raise the temperature of 1 lb. of water at 39° + F. through 1° F. This number 778 expressed in degrees Centigrade becomes

$$\frac{9}{5} \times 778 = 1400 \text{ ft.-lbs.},$$

or in metric units $\frac{1400}{3.28} = 427$ kilogramme-metres.

This number 427 kilogramme-metres represents the amount of work done equivalent to the work expressed in heat, necessary to raise the temperature of one kilogramme of water at 4° C. to 5° C. and this value expressed in gramme-centimetres is 42,700.

These figures follow from the consideration that

$$\text{No. of degrees F.}^\circ = \frac{9}{5} \text{ no. of degrees C.}^\circ + 32,$$

$$1 \text{ ft.} = \frac{1}{3.28} \text{ metre},$$

and

$$1 \text{ cm.} = \frac{1}{100} \text{ metre}.$$

In the change of units from one system to another, it is not necessary to consider the change in the unit of mass, as the mass of water that is raised in temperature changes in the same ratio.

Under the watt, it was seen that 1 gr.-cm. was equal to 981 ergs, and therefore the mechanical equivalent in the C. G. S. system is

$$\begin{aligned} 42{,}700 \times 981 &= 4.18 \times 10^7 \text{ ergs} \\ &= 4.18 \text{ joules}. \end{aligned}$$

As the watt is equal to CE or C^2R, and the calorie is equal to 4.18 joules, we have the relation

$$\begin{aligned} 1 \text{ calorie} &= 4.18 \times C^2R \\ &= 4.2 \text{ joules}, \end{aligned}$$

or

$$1 \text{ joule} = .24 \text{ calorie}.$$

This expression is an important one for calculating the rise of

temperature of conductors due to currents flowing in them. The rise in temperature $\theta°$ is calculated from the formula

$$\theta° \text{ (Cent.)} = \frac{.24 \times C^2Rt}{ms}$$

where C, R, and t retain their usual significations, and

m = mass of conductor in grammes, and
s = its specific heat.

To convert		Multiply by	Divide by
Watts into	B. T. U. per sec.	.000954	1,048
" "	joules per sec.	1	
H. P. "	calories per sec.	179.4	
" "	B. T. U. per sec.	.72	

1 H. P. = 33,000 ft.-lbs. per min., and is also equal to 746 watts; therefore,

$$1 \text{ watt} = \frac{33000}{746} = 44.2 \text{ ft.-lbs. per min.,}$$

and the watt being the work at the rate one joule per sec.

$$1 \text{ joule} = \frac{44.2}{60} = .737 \text{ ft.-lbs.}$$

The work in ft.-lbs. done by a current of C amperes flowing through R ohms for t minutes is

$$W = 44.2\ C^2Rt \text{ ft.-lbs.}$$

The number of calories produced by a current C, in resistance R, in time t is

$$H = .24\ C^2Rt.$$

The number of **B. T. U.** produced by a current C, in resistance R, in time t is

$$H^1 = \frac{60 \times .24}{453.9} C^2Rt = .0316\ C^2Rt.$$

The number of joules produced by a current C, in resistance R, in time t is

joules $= C^2Rt$ and
watts $= C^2R$ or, since $CR = E$,
watts $= CE$.

$$
\begin{aligned}
1 \text{ calorie} &= 4.18 \text{ joules} \\
&= 4.18 \times 10^7 \text{ ergs} = 3.086 \text{ ft.-lbs.} \\
&= .00396 \text{ B. T. U.,} \\
1 \text{ B. T. U.} &= 252 \text{ calories} \\
&= 1060 \text{ joules} = 1060 \times 10^7 \text{ ergs} \\
&= 777.7 \text{ ft.-lbs.,} \\
1 \text{ joule} &= .239 \text{ calorie} \\
&= 1 \text{ watt per second.}
\end{aligned}
$$

Examples of Power, Work, and Heat.

1. If 20 amperes flow through a circuit of 10 ohms resistance for an hour, find (1) the heat generated (2) work done in the circuit (3) power absorbed. *Ans.* 3,441,600 calories.
14,400,000 joules.
321.6 H. P.

2. What will be (1) the heat generated (2) work done in a circuit in which a current of 100 amperes causes 50 electrical horse power to be absorbed in 1 hour. *Ans.* 534,882 calories.
2,238,000 joules.

3. Find the potential difference at the terminals of a circuit in which 10 H. P. is absorbed, when a current of 37.3 amperes passes through it. *Ans.* 200 volts.

4. An incandescent lamp of 145 ohms resistance is placed under water in a pail containing 2 kilos of water at 18° C. How long must a current of 2 amperes flow through the lamp in order to raise the temperature of the water to 35° C., provided 98% of the heat goes to raise the temperature of the water.

$$\text{Calories generated} = .24C^2Rt \qquad (1)$$
$$\text{Calories required} = (35\text{-}18) \times 2000 \qquad (2)$$

$$(1) = (2) \text{ or } t = \frac{34000}{2^2 \times 145 \times .24 \times .98} = 249.2^s = 4.15 \text{ min.}$$

5. How much paraffin could be raised in temperature from 10° C. and melted in four minutes by a current of 3 amperes through a wire of 12 ohms resistance imbedded in the paraffin. Ap. heat of paraffin = .2, latent heat = 8, melting point 54° C.

$$\text{Heat generated in calories} = C^2Rt \times .24$$
$$= 9 \times 12 \times 4 \times 60 \times .24 \qquad (1)$$
$$\text{Heat necessary} = M \times .2 \times (54\text{-}10) + M \times 8 \qquad (1)$$
$$(1) = (2) \text{ or } \quad M = 370.3 \text{ grams.}$$

Unit of Capacity.

When an E. M. F. is applied to the terminals of a condenser a certain quantity of electricity will flow into it until it is charged to the same potential as the applied E. M. F. For the present, a condenser may be considered as simply two plates of conducting materials separated by an insulating plate.

In charging such a condenser, current will flow into it only as long as the E. M. F. at its terminals is changing, and a definite change will allow a definite quantity to be held in the condenser. The quality of being able to store this energy is called the capacity of the condenser.

The capacity is defined either in terms of the quantity of electricity which can be held at a certain potential, or in terms of the current which will flow into the condenser when the difference of potential is changing at a certain rate.

A circuit or condenser has a capacity of one C. G. S. unit of capacity when *a rate of change of potential of one C. G. S. unit of E. M. F. per second produces one C. G. S. unit of current,* or a condenser has unit capacity *when it is charged to a potential of one C. G. S. unit by one C. G. S. unit of quantity of current.*

The **practical unit of capacity** is a unit one one-thousand-millionth, 10^{-9}, of the value of the C. G. S. unit of capacity, and is called the **farad,** being named for Michael Faraday, a celebrated English physicist, who lived from 1791 to 1867. A condenser to have the capacity of the farad would be extremely large and a working unit has been adopted, called the **microfarad,** which is one-millionth of a farad.

It may be said that the potential is directly proportional to the charging current and inversely proportional to the capacity. The less the capacity the higher will be the potential for a given current and vice versa.

Example of Capacity.

The E. M. F. in a circuit alternates between 20,000 volts positive and negative, 40 times a second. What current will flow in a conductor if its capacity is 8 microfarads? ***Ans.*** **12.8 amperes.**

Unit of Inductance.

Inductance is the property of an electric circuit by which it resists a change in the current. *When a rate of change of current of one C. G. S. unit per second induces an E. M. F. of one C. G. S. unit, the circuit has unit inductance.*

It will be shown that every circuit carrying an electric current is surrounded by a magnetic field, which is brought into existence by the current. Any change in the current will produce a change in the magnetic field, and this field reacting on the conductor induces an E. M. F. which tends to prevent any change. If the current is increasing, the induced E. M. F. tends to prevent the increase, and similarly when decreasing the induced E. M. F. tends to prevent the decrease.

The induced E. M. F. is directly proportional both to the rate of change of current and to the inductance. The induced E. M. F. acts as a counter E. M. F. to the applied E. M. F. producing the current. If a certain current is flowing in a circuit of certain inductance, the E. M. F. required to reverse it in a given time may be calculated.

The **practical unit of inductance** is a unit of one-thousand millions, 10^9 times as great as the C. G. S. unit of inductance, and is called **a henry,** being named for Joseph Henry, an American physicist, who discovered many of the laws of magnetic induction.

Examples of Inductance.

1. **The current in a circuit is changed from 0 to 50 amperes in .005 second. The average induced E. M. F. is 10 volts. What is the inductance of the circuit?** *Ans.* 1 Millihenry.

2. **How many average volts are required to reverse a current of 50 amperes in a circuit of 5 henries inductance in .5 of a second?** *Ans.* 1000 volts.

International or Legal Units.

As a result of an International Congress of Electricians held in 1893, the following units were adopted, these being approved and adopted in June, 1894, by the United States Congress:

1. The **unit of resistance,** the international ohm, which is based

upon the ohm equal to 10^9 units of resistance of the C. G. S. system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area, and of a length of 106.3 centimetres.

If the mass of one cubic centimetre of water at 4° C. is one gramme, the area of cross-section of such a column will be one square millimetre.

2. The **unit of current,** the international ampere, which is 10^{-1} of the unit of current of the C. G. C. system of electromagnetic units, and which is represented sufficiently well for practical use by the unvarying current, which, when passed through a solution of nitrate of silver, in water, and in accordance with standard specifications, deposits silver at the rate of .001118 gramme per second.

The anode in the solution is pure silver, the kathode pure platinum, and the liquid is a neutral solution of pure silver nitrate, containing about 15 parts by weight of the salt to 85 parts by weight of water.

3. The **unit of electromotive force,** the international volt, which is the E. M. F. that steadily applied to a conductor, whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the E. M. F. between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C. and prepared in a manner according to standard specifications.

The Clark's cell consists of zinc and mercury in a saturated solution of zinc sulphate ($ZnSO_4$, $7H_2O$) and mercurous sulphate in water, prepared with mercurous sulphate in excess, all held in a small glass jar. The E. M. F. is determined at any temperature t° C. by the formula

$$E = 1.4342\ [1 - .00077\ (t - 15)].$$

4. The **unit of quantity,** the international coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.

5. **The unit of capacity,** the international farad, which is the capacity of a conductor charged to a potential of one international volt by one international coulomb of electricity.

6. **The unit of work,** the joule, which is 10^7 units of work in the C. G. S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ohm.

7. **The unit of power,** the watt, which is equal to 10^7 units of power in the C. G. S. system and which is represented sufficiently well for practical use by the work done at the rate of one joule per second.

8. **The unit of induction,** the henry, which is the induction in the circuit when the E. M. F. induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second.

CHAPTER II.

RESISTANCE.

All kinds of matter, whether solid, liquids, or gaseous, offer a resistance to the passage of electricity. An electric current cannot flow unless a difference of electric potential exists, nor can a current flow without encountering some resistance. The definition of the International Unit of Resistance, the ohm, is based on the fact that a certain column of mercury at a certain temperature has a given definite resistance, or it offers at that temperature a certain obstruction to the passage of electricity.

Those substances which offer little resistance to electric currents are called **conductors,** and those which offer great resistance are called **insulators.** Between these extremes are certain substances which are partly conductors and partly insulators and which are called **partial conductors.**

Table of Conductors.

Good Conductors.

Silver,	Lead,	Manganin,
Copper,	Mercury,	Brass,
Aluminum,	Carbon,	Bronze,
Zinc,	Water,	Phosphor Bronze.
Platinum,	German Silver,	
Iron,	Platinum Silver,	

Partial Conductors.

The Body,	Cotton,	Dry wood,	Paper.

Uses of Conductors.

Most of these conductors find some use in the electrical apparatus and instruments installed on board ship.

Copper is used in the dynamo and motor windings, electric light

and power mains, switchboards, bus bars, switches, interior communication circuits, and in general where high conductivity is required and full of potential small. It is particularly adapted for conductors on account of its high conductivity, its abundance, and the ease with which it is worked into various shapes. For conductors it is generally of the wire, ribbon, or bar shape.

Zinc finds its principal use in the anodes of electric batteries.

Platinum conductors are used in incandescent lamps as connecting wires between the copper leading wires and the carbon filaments. Alloys of platinum are used in some forms of rheostats.

Brass or **bronze** finds use for conductors on switchboards, and in the various terminals of dynamo leads on headboards and switchboards and as the interior fittings in water-tight appliances. The conductors, however, for these are copper.

Lead or an **alloy of lead** is used for conductors in the numerous fuses placed in different parts of dynamo or motor circuits to protect the circuits against excessive current.

Carbon is used for conductors in dynamo and motor brushes, in contact pieces for circuit breakers and in the searchlights and arc lamps.

Manganin is used in the resistances of voltmeters and ammeters.

German silver finds use in rheostats, resistance coils, and parts of apparatus where high resistance is required. Its general composition is:

Copper	4 parts.
Nickel	2 parts.
Zinc	1 part.

The variation of the resistance of German silver due to changes of temperature is very small, its coefficient per degree rise in temperature C.° being about nine times less than that of copper. Strong currents continually used in German silver resistances tend to make the conductors brittle.

Phosphor bronze is used in the clips of switches to prevent blisters forming, due to the arc on opening the switch. In some cases it has been used for commutator segments, but they are usually now made of hard drawn copper.

Laws of Resistance.

Experiment shows that the two following laws hold in the case of conductors:

First Law.—The resistance of a given conductor of uniform section at a constant temperature is directly proportional to its length.

Thus if l represents length and R resistance, then R varies directly as l, or

$$R \propto l.$$

If a conductor of a certain length has a certain resistance, then a conductor twice as long, of the same area of cross-section, at the same temperature, will have a resistance twice as great; and if half as long, it will have a resistance half as great.

Second Law.—The resistance of a given conductor at constant temperature is inversely proportional to its sectional area.

If, as before, R represents resistance and a area of cross-section, then R varies *inversely* as a

$$R \propto \frac{1}{a}.$$

If a conductor of a certain area of cross-section at a certain temperature has a certain resistance, then a conductor of twice the area of cross-section, at the same temperature, will have a resistance one-half as great; and if half its area of cross-section, it will have a resistance twice as great.

From a consideration of the above laws, it is seen that R varies directly as the length and inversely as the area of cross-section of the conductor, or

$$R \propto \frac{l}{a}.$$

In order that this equation may give the value of R in ohms and be a pure equation rather than a proportion, it is necessary to multiply it by a *constant* for the particular material of the conductor and temperature at the time.

This constant is called the **specific resistance** of the conductor at the temperature and is defined as *the resistance in ohms of unit length of the conductor having unit cross-sectional area.*

The unit adopted is both the inch and the centimetre, so that the

specific resistance is the resistance in ohms per cubic inch or per cubic centimetre of the conductor, or it is the resistance in ohms between the opposite faces of a cube, either one inch or one centimetre on the side.

Combining the laws of resistance with the definition of specific resistance, we have the fundamental equation of resistance

$$R = \rho \frac{l}{a} \tag{1}$$

where ρ represents the specific resistance of the conductor at a certain temperature.

Thus the resistance of any conductor may be found if its specific resistance, length, and area of cross-section is known.

In cases where it is inconvenient to measure the length, as in a long coil, it may be weighed and l found from the expression

$$l = \frac{w}{ad} \tag{2}$$

where w = weight in grammes,
a = area in sq. cm.,
d = specific density,

R then becomes, by substituting the value of l from (2) in (1)

$$R = \rho \frac{w}{a^2 d}.$$

The specific resistance is usually stated in microhms; thus, that of lead is 19.63 microhms, or .00001963 ohms expressed in C. G. S. units.

Table of Specific Resistances.

Substance at 0° C.	Sp. resist. microhms—per cm. cube.	Relative Conductivity.
Copper (annealed)	1.57	100
Copper (hard)	1.60	98
Silver	1.49	105
Platinum	8.98	17
Iron	9.638	16
Lead	19.63	8.3
Mercury	94.34	1.6
Carbon (arc light)	4000	$\frac{1}{2500}$
German Silver	20.76	7.6
Platinoid	30 to 36	
Glass	91×10^{18}	less than $\frac{1}{1,000,000,000}$
Gutta-percha	4.5×10^{20}	same.

Table of Resistances of Chemically Pure Metals at 0° C. in International Ohms.

Name of metal.	Resist. of a wire 1 ft. long $\frac{1}{1000}$" in diameter.	Resist. of a wire 1 metre long 1 millimetre in diameter.
Silver, annealed	9.0283	.01911
" hard drawn	9.8028	.02074
Copper, annealed	9.5877	.02029
" hard drawn	9.8068	.02075
Gold, annealed	12.3522	.02614
" hard drawn	12.5692	.0266
Aluminum, annealed	17.4825	.037
Zinc, pressed	33.7614	.07145
Platinum, annealed	54.3517	.11503
Iron, annealed	58.308	.12342
Lead, pressed	117.79	.24921
German Silver	125.6139	.26588
Platinum Silver	146.3621	.30979

German silver, an alloy of copper, nickel, and zinc, combined with 1 to 2 per cent of tungsten is known as platanoid. The addition of tungsten gives the alloy greater density and reduces tendency to oxidation. The alloy takes a polish like silver.

Any foreign matter considerably reduces the conductivity of metals and alloys usually show higher resistances than any of their constituents. As a rough unit, a mile of copper wire, $\frac{1}{4}$" diameter has a resistance slightly less than one ohm.

Relation of Heat and Resistance.

Generation of Heat.—One effect of a current of electricity on a conductor is to produce heat in the mass of the conductor, the number of joules developed being given by the equation C^2Rt. The greater the current, the higher the resistance and longer the time, the greater the increase of heat and consequent rise of temperature.

If the heat is carried away by conduction or radiation as fast as developed its temperature will not rise; or, if after a certain temperature has been attained, the heat is carried away as fast as developed, the conductor will remain at that temperature; but if the heat cannot be dissipated, the conductor will get hotter and hotter until its melting point is reached.

Table of Melting Points.—The melting point of some of the most important conductors are in degrees C.

Alloy, 3 lead, 2 tin, 5 bismuth	93°
Alloy, 1½ tin, 1 lead	168°
Alloy, 1 tin, 1 lead	240°
Tin	230°
Lead	325°
Aluminum	625°
Bronze	922°
Silver	945°
Gold	1045°
Copper	1054°
Cast Iron	1135°
Steel	1380°
Steel, hard	1410°
Wrought iron	1600°
Platinum	1775°

The current that will melt copper wire is given by the formula

$$C = 80d^{\frac{3}{2}}$$

where

C = current in amperes,

d = diameter of conductor in millimetres,

or

$$C = .325d^{\frac{3}{2}}$$

where

d = diameter in thousandths of an inch.

The diameter in inches of a *lead* conductor that will melt with a given current is equal to the cube root of the square of the quotient of amperes divided by 1379. For *half and half* solder the divisor is 1318.

Variation of Resistance with Temperature.—It is to be noted that the table of specific resistances is for materials at a certain temperature, 0° C. This is necessary from the fact that the resistance of any substance, conductor or insulator, depends on the temperature at any given time.

The resistance of all the metals, and with few exceptions of all the alloys, increases with rise of temperature. Non-metals, such as

the solids, carbon, sulphur, silicon, phosphorus, etc., and the principal gases, oxygen, hydrogen, nitrogen, chlorine and its family all decrease in resistance for a rise of temperature. Also the resistance of liquids that can be electrolyzed decreases for a rise of temperature.

Resistance Temperature Coefficient.—The **resistance temperature coefficient** is defined to be *the amount of increase or decrease of resistance in ohms which one ohm in any substance would undergo for each degree Centigrade change of temperature.*

The resistance of conductors increases with temperature in accordance with the following empirical formula:

$$R = r(1 + at \pm bt^2)$$

where

R = resistance at temperature t,
r = resistance at temperature 0° C.,
t = temperature in degrees C.,
a, b = temperature coefficients of the conductor.

It is usually sufficient to disregard the last term and use

$$R = r(1 + at). \qquad (a)$$

It is ordinarily sufficient to regard t as the difference between any two temperatures, and then r becomes the resistance at the lower and R at the higher temperature.

The temperature coefficient a is positive for all elementary metals except carbon and for most pure metals has an average = .004 between 0° C. and 100° C.

As a general rule, if two or more elements form an alloy, it has a higher specific resistance and lower temperature coefficient than any of its component elements.

The increase in temperature of copper conductors, apart from the increased resistance, is an important factor in calculating the size of conductors to carry certain currents, as they must be large enough to carry their currents with overheating.

Formula (a) may be used to determine the increase in temperature of conductors due to current, by measuring the resistance both when hot and cold. Then knowing the temperature coefficient, the increase in temperature t may be calculated.

The effect of a change in temperature shows that it is important to know the resistance of certain conductors when current is flowing, as the different windings of dynamos and motors, of rheostats, regulators and starting boxes, and particularly it is required to know the *hot* resistance of incandescent lamps, so that the current a lamp is absorbing when it is giving its rated candle-power may be known.

Temperature Correction for Copper Conductors.—A simple formula for finding the resistance of a copper conductor at any temperature is given below.

$$R_t = \frac{LK}{d^2}$$

where

R_t = resistance at temperature t,
L = length of conductor in feet,
d = diameter of conductor in mils,
d^2 = area of conductor in cir. mils,
K = a calculated constant.

K is given in the following table for certain temperatures; the temperatures being calculated from assumed values of K, this being the resistance in ohms of one mil-foot, assuming that the resistance of one mil-foot of pure copper wire is 9.162 ohms at 0° C.

Resistance per mil-foot in ohms K.	Temperature, degrees Centigrade.
10.00	10.26
10.10	12.86
10.20	15.44
10.30	18.00
10.40	20.54
10.50	23.06
10.60	25.56
10.70	28.04
10.80	30.50
10.90	32.95
11.00	35.38
11.10	37.80
11.20	40.20
11.30	42.58
11.40	44.95
11.50	47.30

If the temperature is given in degrees Fahrenheit, it must be reduced to degrees Centigrade by using the formula

$$C = \frac{5}{9}(F - 32).$$

Thus suppose it was required to find the resistance at 64.4° F. of 100 feet of copper wire 4000 cir. mils in area. First reduce 64.4° F. to degrees C. thus

$$C = \frac{5}{9}(64.4 - 32) = 18°.$$

The value of K corresponding to 18° C. is 10.30, so

$$R = \frac{100}{4000} \times 10.30 = .2575 \text{ ohm.}$$

The value of K to be used in the formula is the one that corresponds most nearly to the given temperature; or the exact value for any temperature may be found by interpolation.

Suppose we want to find the value of K corresponding to $t = 36°$ C. The difference in K for a difference of 37.80 — 35.38 = 2.42 t is (11.10 — 11.00) = .1 or for 1t it is $\frac{.1}{2.42}$ and for (36 — 35.38) = .62t the difference is $\frac{.62 \times .1}{2.42} = .0256$, which added to the value of K for 35.38° becomes 11.0256.

Problems on Resistance.

1. Find the resistance at 25° C. of a copper wire 10 metres long and 1 mm. in diameter. The resistance of copper increase by .39% for each degree rise of temperature. Sp. resistance of copper = 1600 C. G. S. units.

$$R_0 = \rho \frac{l}{\pi r^2} = 1600 \times \frac{10 \times 100}{\pi} \times \frac{1}{(.05)^2} = 2.0378 \times 10^9 \text{ C. G. S. units}$$

$$\text{or } R_0 = \frac{2.0378 \times 10^9}{10^9} = .2037 \text{ ohm}$$

$$R_{25°} = .2037\ (1 + 25 \times .0039) = .2236 \text{ ohm.}$$

2. A uniform glass tube 92.1 cm. in length was filled with mercury and the resistance of the column of mercury was measured and found to be 1.059 ohms. The weight of the mercury contained in the tube was 10.15 grms. Calculate from this experiment the specific resistance of mercury, taking its specific gravity as 13.6.

Ans. 93177 C. G. S. units

3. The resistance of a bobbin of wire is measured and found to be 68 ohms; a portion of the wire 2 metres in length is now cut off and its resistance is found to be .75 ohm. What was the total length of wire on the bobbin?

$$R = \rho \frac{l}{\pi r^2} = 68 \qquad R' = \rho \frac{l'}{\pi r^2} = .75$$

$$\text{or } \frac{l}{l'} = \frac{68}{.75} \qquad l = \frac{200 \times 68}{75} = 181.3 \text{ metres.}$$

4. The resistance at 0° C. of a column of mercury 1 metre in length and 1 sq. mm. in cross-section is called a "Siemens unit". Find the value of this unit in terms of the ohm. Sp. resistance of mercury = 94,340 C. G. S. units. *Ans.* .9434 ohm.

5. What length of platinum wire 1 mm. in diameter is required to make a one ohm resistance coil? Sp. resistance platinum = 9000 C. G. S. units. *Ans.* 872.8 cms.

Problems on Heat and Resistance.

1. Suppose a chain made of alternate links of silver and platinum, each .2 mm. thick. What current will keep the platinum red hot, 500° C.? What will be temperature of the silver?

Specific resistance of silver = 1.634 microhms; of platinum = 9.957 microhms; radiation per sq. cm. of surface per sec. per degree rise of temperature = .001 joule.

$$\text{Resist. of platinum link} = \rho \times \frac{l}{\pi r^2} = \frac{9.957}{10^6} \times \frac{l}{\pi (.01)^2}.$$

$$\text{Joules radiated per sec.} = \frac{1}{1000} \times 500 \times \pi \times .02 \times l = \frac{\pi l}{100}. \quad (1)$$

$$\text{Joules generated per sec.} = C^2 R. \quad (2)$$

$$(1) = (2) \qquad \text{or } C^2 = \frac{\pi l}{100} \times \frac{\pi}{9.957} \times \frac{10^2}{l} = \frac{\pi^2}{9.957}$$

$$\text{or } C = .9956 \text{ amperes.}$$

$$\text{Joules radiated per sec. in silver} = (t - 0) \times \frac{1}{1000} \times \pi \times .02 \times l. \quad (1)$$

$$\text{Joules generated per sec. in silver} = C^2 R = (.9956)^2 \times \frac{1.634}{10^6} \times \frac{l}{\pi (.01)^2}.$$

$$(1) = (2) \qquad \text{or } t = \frac{1.634 \times 10^2}{9.957 \times 2} = 82.05° \text{ C.}$$

2. On a certain circuit on board ship there are 15 lamps each taking .7 ampere and a margin of 25% excess of current is allowed. Find the diameter of a lead safety fuse for this circuit. Sp. resist. of lead = 19.85 microhms, melting point 335° C.; loss of heat by radiation and connection per sq. cm. of surface .001 joule per sec. per degree rise of temperature. Initial temperature 18° C.

$$\text{Current allowed for} = 15 \times .7 + \frac{15 \times .7}{4} = 13.125 \text{ amperes.}$$

$$\text{Resistance of fuse} = \rho \times \frac{l}{\pi r^2} = \frac{19.85}{10^6} \times \frac{4l}{\pi d^2}.$$

Joules generated by current per sec.

$$= C^2R = (13.125)^2 \times \frac{19.85}{10^6} \times \frac{4l}{\pi d^2}. \quad . \quad (1)$$

Joules carried away by radiation

$$= \frac{(335 - 18) \times \pi dl}{1000}. \quad (2)$$

(1) = (2) or $d^3 = \frac{(13.125)^2 \times 19.85 \times 4 \times 1000}{317 \times \pi^2 \times 10^6}$

$$d = .1635 \text{ cm.}$$

3. A potential galvanometer has a resistance of 367 ohms and is graduated to show a difference of potential of 100 volts between the terminals. Find the diameter of a lead safety fuse which will melt if the potential difference rises above 100° C. Temperature of room 20° C., other data as in example 7. *Ans.* $d = .01237$ cm.

4. On a circuit there are 65 incandescent lamps in parallel, each lamp requiring .6 ampere. If a margin of 30% excess of current is allowed, find the diameter of a lead safety fuse to be inserted in the mains. Temperature of room 20° C., other data as in example 7.

Ans. $d = .4034$ cm.

5. If a ward room is supplied with 30 lamps, each taking .8 ampere and a margin of 20% is allowed for, what should be the diameter of a lead safety fuse to protect this circuit? Temperature of room 18° C., other data as in example 7. *Ans.* $d = .2761$ cm.

Temperature Coefficient of a Circuit.

An electrical circuit is ordinarily made up of resistances combined in one or more ways and it will be seen later how the different resistances of a circuit may be combined in *series,* in *parallel,* or in a combination of these, and how the value of the resistances may be calculated.

In certain cases the temperature coefficient of parts of a combined circuit may be required, as when the resistances are made up of conductors of different materials.

Two Resistances in Series.—The case of two conductors of different materials joined in series is shown in Fig. 2.

R_1 and R_2 represent the resistances of the two different conductors joined in series and let a_1 and a_2 represent the temperature coefficients of R_1 and R_2.

The total *increase* or *decrease* of R_1 will be a_1R_1 per 1° C., while that for R_2 will be a_2R_2 per 1° C., and consequently the resistances of each for 1° C. rise will be $R_1 \pm a_1R_1$ and $R_2 \pm a_2R_2$.

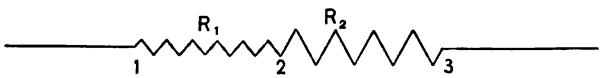


FIG. 2.—Two Resistances in Series.

The *combined temperature coefficient,* which is defined as the ratio of the increase or decrease for 1° C. to the original resistance, is called a, and

$$a = \frac{R_1 \pm a_1R_1 + R_2 \pm a_2R_2 - (R_1 + R_2)}{R_1 + R_2}$$

or

$$a = \frac{a_1R_1 \pm a_2R_2}{R_1 + R_2} \text{ ohm per ohm per } 1° \text{ C.}$$

If a_1 is positive and a_2 negative, and $a_1R_1 = a_2R_2$ $a = 0$, or the total resistance of $R_1 + R_2$ will be constant at all temperatures, a result of great importance in the construction of certain electrical measuring instruments.

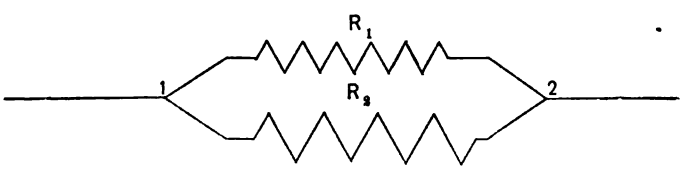


FIG. 3.—Two Resistances in Parallel.

Two Resistances in Parallel.—The case of two conductors of different material joined in parallel is shown in Fig. 3.

As before R_1 and R_2 represent the original resistances of the two conductors of different materials joined in parallel and a_1 and a_2 the temperature coefficients of R_1 and R_2.

It will be shown that the combined resistance of R_1 and R_2 from 1 to 2 is

$$\frac{R_1 R_2}{R_1 + R_2}.$$

The total increase or decrease of R_1 and R_2 will be $a_1 R_1$ and $a_2 R_2$ per 1° C., and the combined resistance for a change of 1° C. will be

$$\frac{(R_1 \pm a_1 R_1)(R_2 \pm a_2 R_2)}{(R_1 \pm a_1 R_1) + (R_2 \pm a_2 R_2)}$$

and the change in resistance due to 1° C. change will be

$$\frac{(R_1 \pm a_1 R_1)(R_2 \pm a_2 R_2)}{(R_1 \pm a_1 R_1) + (R_2 \pm a_2 R_2)} - \frac{R_1 R_2}{R_1 + R_2}$$

and the temperature coefficient for the combined circuit a_1 will be

$$a = \frac{\dfrac{(R_1 \pm a_1 R_1)(R_2 \pm a_2 R_2)}{(R_1 \pm a_1 R_1) + (R_2 \pm a_2 R_2)} - \dfrac{R_1 R_2}{R_1 + R_2}}{\dfrac{R_1 R_2}{R_1 + R_2}}$$

and this reduces to

$$a = \frac{(R_1 + R_2)(1 \pm a_1 \pm a_2 \pm a_1 a_2)}{R_1 + R_2 \pm a_1 R_1 \pm a_2 R_2} - 1 \text{ ohm per ohm per } 1° \text{ C.}$$

Conductivity.

Conductivity is the name given to express the ease with which substances conduct electricity. A substance of high conductivity has low resistance and vice versa, and conductivity is the reciprocal of resistance.

The **unit of conductivity** is called the **mho**, and is the reciprocal of the ohm. It is the conductivity of a conductor whose resistance is one ohm.

A consideration of the laws of resistance will show that similar laws hold for conductivity, and are embraced in the formula

$$K = \frac{a}{\rho l}.$$

The *specific conductivity* is the conductance between opposite faces of a cube, one inch or one centimetre on the side.

Resistance of Series and Parallel Circuits.

As previously stated, electric circuits consist of conductors of various resistances connected in one or more ways to form one or more complete paths for the flow of the electric current, and the combined or total resistances of the various branches depend on the manner in which they are joined.

There are two main systems of arranging conductors, called **series system** and **parallel system,** and a complete circuit may be of a complete system of either or a combination of both.

Resistances in Series.—Conductors are joined in series, when the end of one is connected to the end of another, all in one line, or connected *end on* to one another, as indicated in Fig. 4.

FIG. 4.—Resistances in Series.

Any current that flows from A to B must flow through each of the several resistances in turn, and the same current must flow through them all. The resistance of one is additive to another and it is plainly evident that the total resistance of any number of separate resistances connected in series is equal to the sum of their separate resistances. Thus the resistance from A to B is

$$R_1 + R_2 + R_3 + R_4 + R_5 .$$

It is also evident that it matters not in what order the resistances are joined, as the addition of each resistance is a positive increase to the total resistance.

Resistances in Parallel.—Resistances are connected in parallel when one or more branches of the circuit are connected to the same points of the circuit. This is illustrated in Fig. 5.

Three resistances R_1, R_2, and R_3 are connected to the same points of the circuit, at A and B and it is required to find the combined resistance of the three, or the resistance of a single conductor joining A and B that would allow the same current to flow in the circuit to which A and B are connected.

The *conductance* of R_1 is $\frac{1}{R_1}$ and similarly for R_2 and R_3, and it is evident that the conductance from A to B is the sum of the conductances of the various branches, or the total conductance from A to B is

$$K = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

and as the total conductance is the reciprocal of the total R,

$$K = \frac{1}{R},$$

or

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

and

$$R = \frac{R_1 R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}.$$

If

$$R_1 = R_2 = R_3$$

$$R = \frac{R_1}{3} = \frac{R_2}{3} = \frac{R_3}{3}.$$

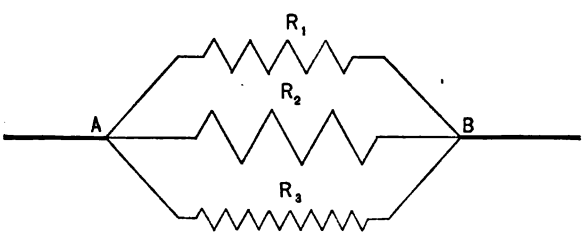


FIG. 5.—Resistances in Parallel.

As there are now equal paths for the current to flow, it is the same as though the three resistances had been replaced by one of three times the cross-sectional area, and it has been shown that resistance varies inversely as the area, so if the area is three times as great as one, the resistance would be one-third of each of the conductors.

Resistances in Series and Parallel.—The most common arrangement of conductors in an electrical circuit is a combination of the series and parallel systems as indicated in Fig. 6.

The resistance from A to B of such a circuit is the sum of all the resistances of the several parts, thus from A to B is equal to resistance from A to C + that from C to D + that from D to B, and as above, total resistance is

$$R = R_1 + \frac{R_2R_3R_4}{R_2R_3 + R_2R_4 + R_3R_4} + R_5 .$$

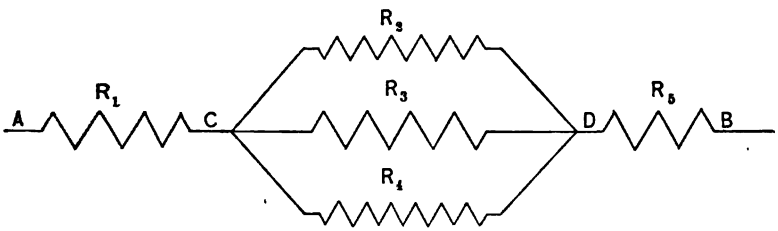


FIG. 6.—Combined Series and Parallel Resistances.

Resistance of Joints and Imperfect Contacts.

When two dissimilar conductors are joined together either by birding screws or soldering, and a current passed from one conductor to the other, their junction will be either heated or cooled, dependent on the direction in which this current is flowing. Conversely, if this junction be either heated or cooled, a current will be set up, flowing in a direction dependent on the material of the conductors. This heating effect is very small and does not arise from any resistance the current meets at the junction of the conductors. It is simply mentioned in order to distinguish it from the resistance that all joints do give rise to, some more than others.

It is impossible to compute what is the extra resistance added to a circuit due to imperfect joints or contacts, the resistance varying with the goodness or poorness of contact. It should be seen that all joints and connections are perfectly tight, for the less nearly perfect they are, the greater the resistance, the more heat developed in them and consequently more energy uselessly wasted. Loose joints in an electric-light circuit will often cause a fluttering of the lights, and many causes may be sought, when it is only such a little thing as a loose connection on the switchboard.

One form of a rheostat is composed of carbon blocks, which by varying the pressure on them alters the resistance of their contacts and so alters the current in the circuit.

Insulation.

Insulation is defined as the means adopted for preventing electric currents from acting along any other path than through the conductors provided for the purpose. Insulators are simply substances which are poor conductors of electricity, though even the best insulator has some conductivity, just as the best conductors have some resistance.

The amount of electricity which insulators allow to pass through them is called the **leakage**, and this takes place through the whole cross-section of the insulation, and along the film of moisture on the outside surface of the insulation.

Dirt and moisture act against good insulation, and whenever possible insulators should be highly polished to prevent dirt from sticking, and they should be coated with some form of non-absorbent to prevent the formation of moisture.

The resistance to leakage is obviously the resistance of the insulator, and is given by the same formula as resistance of conductors,

$$R = \frac{\rho l}{a}.$$

Therefore, the longer the insulator and the smaller the area of cross-section, the greater the resistance, or the more efficient the insulator.

Properties of Insulators.—The first requisite of all insulators is of necessity high insulation resistance. This should be combined with waterproof and fireproof qualities, and with toughness and flexibility. For use with high potentials, insulators should have sufficient dielectric strength to prevent rupture from sparking.

Heat affects very materially the insulating properties of substances and in some cases it may alter the chemical composition of insulating compounds. The insulation of some substances change with the degree of electrification, in which cases, heat has a greater

effect. In testing the insulation of electrical conductors the resistance is not measured until at least a minute has elapsed after the conductor is charged.

Table of Insulators.

Oils,	Wool,	Resin,	Glass,
Shellac,	Silks,	Mica,	Air.
Varnish,	Rubber,	Paraffin,	
Porcelain,	Cotton,	Ebonite,	

Uses of Insulators.

Rubber.—Some form of rubber, either gutta-percha, India rubber, pure rubber, or vulcanized rubber is universally used as the principal insulation for copper conductors. Hard rubber is used for washers in the disc or cylindrical form, for switch handles, rheostat arms, and the bases of instruments. The ease with which it can be pressed or molded into shape makes it particularly useful for many purposes. All bushings through bulkheads or beams are made of hard rubber.

Porcelain is used in certain forms of rheostats with the conductors imbedded in it, and for the bases on which rest interior fittings of wiring appliances. Many washers are made of porcelain or some form of earthen ware and used under screw heads or bolts. Porcelain, marble, or slate is used for the foundation of switch-boards and panel boards. It is also used for insulators to carry cables where conduit or molding is not used.

Mica is used for the insulation between segments of the commutator of dynamos and motors, in wiring appliances under the fittings, and for covers of fuse boxes.

This is an excellent insulator; does not deteriorate with high temperature and has a high resistance to sparking, and is also practically non-hygroscopic. It can be made in thin sheets or built up in layers of any desired thickness, and can be made pliable by interposing insulating varnish made from shellac or resin between sheets.

Cotton is used in the form of thread on conductors and in the piece for insulation of certain parts of armatures, particularly the conductors and on the core.

Shellac is used where a light insulation is required and in connection with other insulators. It is rarely used by itself and is generally used as an outside covering to prevent the accumulation of moisture. Armature laminations are insulated with shellac.

Paraffin is used to cover the resistance coils in resistance boxes, offering at the same time good mechanical protection, as it is put on in the liquid state and covers all parts of the coils.

Glass is used as the dielectric for condensers used in wireless telegraphy sets.

Oils are used for insulation where high potentials are carried. The secondary coils of induction coils and certain glass-plate condensers used in wireless telegraphy outfits are often contained in receptacles which are filled with oil.

Different kinds of **paper, cardboard,** or **pressboard** are for armature insulation.

Okonite or some form of rubber forms the base of many insulating tapes and is applied to cotton tape.

A very good flexible insulation, with fairly high resistance, can be made by heating fibrous material with linseed or other oil, drying and finally thoroughly baking it.

Vulcabeston, a mixture of rubber and asbestos, is a very good insulator and satisfies most of the requirements. It is unaffected by high temperatures, does not absorb moisture, is very hard and strong, and has high dielectric strength.

CHAPTER III.

PRIMARY BATTERIES.

Batteries, defined as combinations of electric cells, are of two general classes, primary and secondary or storage batteries. Of these two general classes, the former is the only one that has found any extensive use on board ship, though even its uses are constantly being curtailed by means of current from the dynamos. They are still used for bell work, telephone circuits, for firing guns and torpedoes and for exploding electric mines.

Primary Cells.

Electric cells all generate electricity by chemical action and the term cell is applied to an arrangement in which one or more substances forming a fluid or dry mixture act upon two different metals, or a metal and carbon placed in the mixture, whereby a difference of potential is produced between the metals, a condition necessary to the performance of electric work.

If a piece of metal is placed in a fluid called an electrolyte, there is at once produced a difference of electrical condition of such a kind that the metal either takes a higher or lower potential than the fluid. If two pieces of different metals are placed in the electrolyte, a condition may be produced of one metal assuming a higher potential than the liquid and the other a lower, in which case if the two metals are connected by a conductor outside the liquid, there will be a current of electricity established. The current proceeds from the metal which has a higher potential than the liquid, or the metal which is most actively acted upon chemically by the electrolyte.

Simple contact of dissimilar metals will give rise to a difference of potential, and all metals may be arranged in a table so that any one element in the list will be electropositive to any one below it;

or, in other words, will be of an absolute higher potential than any below it when they are placed in contact. One being electropositive to the other means that if a current flows it will be *from* the one which is electropositive to the other.

Table of Electrochemical Series.

1. Aluminum,	7. Tin,	13. Platinum,
2. Manganese,	8. Copper,	14. Carbon,
3. Zinc,	9. Hydrogen,	15. Chlorine,
4. Iron,	10. Mercury,	16. Oxygen.
5. Nickel,	11. Silver,	
6. Lead,	12. Gold,	

In this table the difference of potential caused by the contact of any two elements is equal to the sum of the differences of potential caused by the contact of all the elements that are between them in the list. Thus the difference of potential caused by the contact of zinc and lead is equal to the sum of the differences caused by the contact of zinc and iron, iron and nickel, and nickel and lead.

Electrolyte.—The electrolyte must be a substance that will act chemically upon at least one of the elements placed in it, and it may be either a chemical acid or a chemical salt. The object of the electrolyte is to increase the difference of potential between the elements placed in it, and by chemical action to keep the difference of potential constant, so that when the electric circuit is completed, a continuous current may be the result.

The real source of energy seems to be in the element that is acted upon most actively chemically, the other element acting as a hand dipping into the liquid to gather and direct the electric current. The electric energy is represented by the wasting away or the consumption of the element of high potential, and the real starting point of the current is at the surface of this element.

Simple Examples of Electrochemical Action.

An examination of the table of electrochemical series shows that iron is electropositive to copper, so that if these two metals are in direct contact, a difference of potential arises causing a current that

will be represented by the wasting away or pitting of the more electropositive one, iron. If these two elements are brought in contact by salt water, we have all the elements for a simple galvanic cell, and the effects of this combination are plainly shown in some copper-sheathed ships, the iron near the sheathing becoming pitted and eaten away. The same effect is seen in the pittings of copper pipes in the salt-water system, the pitting of the copper being due to the fact that copper is electropositive to the chlorine in the salt water. Where copper pipes come through the side of iron ships, it is usual to separate them by zinc rings, so that the zinc-copper combination will prevail over the iron-copper combination and the zinc will be consumed rather than the iron. These zinc plates may be renewed from time to time so as to protect the iron.

Definitions.

The following general definitions apply to all single cells:

The **cell** is the shell, cup or vessel that contains the elements and the exciting fluid. It may be made of glass, porcelain, earthenware or metal.

The **plates** are the elements, metal or carbon pieces that dip into the electrolyte, and are generally referred to as the *electrodes.*

The **electrolyte** is the liquid or dry mixture which acts chemically on the electrodes. In general it is a liquid that is decomposed by a current passing through it.

The **poles** are the portions of the electrodes that project from the electrolyte.

The **terminals** are mechanical devices by which conductors are secured to the poles.

The electrodes are distinguished by one being called positive +, the other negative —, the positive one being the one coming first in the Table of Electrochemical Series.

The **anode** is the positive electrode, the one at which the chemical action is the greater and is the plate by which the current enters the liquid.

The **kathode** is the negative electrode and is the one by which the current leaves the liquid.

It should be noted that the positive pole is part of the negative plate, and the positive terminal is on the positive pole, while the negative pole is part of the positive plate and the negative terminal is on the negative pole.

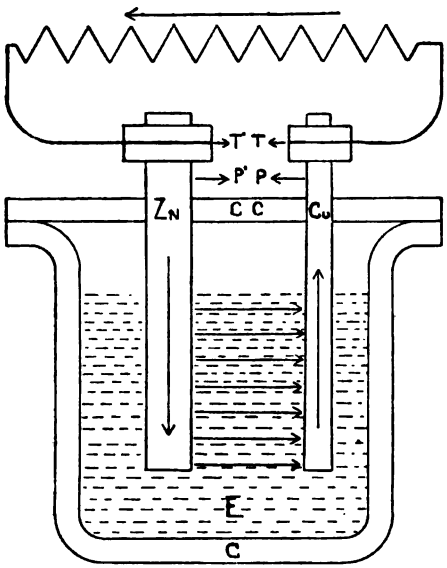


FIG. 7.—Typical Primary Cell.

T = + terminal,	Zn = zinc strip,
T' = — terminal,	= + plate,
P = + pole,	= + electrode,
P' = — pole,	= anode,
CC = cell cover,	Cu = copper strip,
C = cell,	= — plate,
E = electrolyte (exciting fluid),	= — electrode,
	= kathode.

These definitions are illustrated in Fig. 7, showing a simple typical cell with its outside conductor.

The term *cell* is also applied to the whole combination, the cell, electrolyte, electrodes and terminals.

Polarization.

This is the name given to express the weakening of the current when the circuit is closed, due to internal action in the cell, and is generally caused by the collection of bubbles of gas on the kathode. By the chemical action, which takes place between the electrolyte and the anode, gases are liberated from the former and the bubbles are carried across the electrolyte and deposited on the kathode. All gases offer great resistance to electricity, the result being that the current is much weakened, and in some cases polarization almost prevents any current from flowing. If the gases are electronegative to the kathode, they tend to set up an E. M. F. opposed to the original E. M. F. thus still further reducing the current.

Polarization is gotten rid of in three different ways: (1) by mechanical, (2) by chemical, and (3) by electrochemical means; the latter preferably by using a second substance separated from the electrolyte, or by a solution in the electrolyte which will absorb or enter into chemical composition with the liberated gases.

The *depolarizer* is the substance used to prevent or counteract polarization and may be either a solid or a liquid.

Local Action.

This is a name given to the chemical action that goes on in a cell when the circuit is open, that is when the outside circuit is broken. This is a quiet action and is usually due to impurities in the electrodes. It ordinarily arises from particles of iron, arsenic or other foreign metals in the anode, which in most forms is zinc. These impurities being imbedded in the zinc and the zinc and impurities in contact with the electrolyte form little closed circuits which gradually waste away the zinc. It is obviated by using chemically pure zinc, but as this is very expensive, by amalgamating the zinc, that is by giving it a slight coating of mercury. The mercury covers up the impurities and seems to bring only the pure zinc to the surface. The amalgamated surface seems to hold a film of hydrogen gas which acts to protect it from local action at all times.

Electromotive Force of Cells.

As has been stated, the E. M. F. of a cell depends entirely on the electrodes and the electrolyte used. In the contact of dissimilar metals, the difference of potential is due alone to the elements themselves, and not to their size, shape, or other characteristics, and this holds true in an electric cell as far as the E. M. F. is concerned, though the resulting current depends very much on the size, shape, and distance apart of the electrodes.

E. M. F. on Open Circuit.—When the circuit is open the difference of potential between the poles is always equal to the total E. M. F. developed within the cell; or, in other words, the E. M. F. of a cell is the difference of potential between its poles when no current is passing through or from it. When the circuit is closed, the E. M. F. at the poles is less than the total E. M. F. due to the volts lost in driving the current through the internal resistance of the cell, and this point must always be borne in mind in connecting up cells for any particular work.

By Ohm's law, the loss of potential in the cell itself is equal to the current flowing through the cell multiplied by the internal resistance. So if E is the total E. M. F. of a battery due to the battery itself, C the battery current, and r the internal resistance, then the loss of potential or lost volts in the cell is Cr and the available difference of potential at the terminals $E' = E - Cr$.

To measure directly the total E. M. F. of a battery or cell, it must be compared with the E. M. F. of some standard cell, but to obtain the E. M. F. of this standard cell, it must be measured electrostatically by some means, for in all other ways, there must be current drawn from the cell and this will vitiate the result.

Measurement of E. M. F.—The E. M. F. of a cell may be measured directly by means of Sir Wm. Thompson's absolute electrometer, which draws no current whatever from the cell. The principle of this instrument is that of a condenser with one fixed and one movable plate. If these two are connected to two points of an electric circuit, between which there exists a difference of potential, the movable plate tends to move so as to increase the electrostatic capacity of the condenser, and it is moved with a force

proportional to the square of the difference of potential by which the force is produced. The force produced is measured by balancing it against known weights. An ordinary condenser with a galvanometer and key in circuit may replace the electrometer, when comparing the cell with some standard cell.

There are many laboratory ways of comparing E. M. F., all of them requiring some standard cell, or cell whose E. M. F. is accurately known, certain known resistances and a galvanometer. Galvanometers are not furnished on board ship, but a very good substitute may be found in a double reading voltmeter furnished on some ships as a ground detector, and the resistances of the Wheatstone bridge may be used. These will be described later, and having these, one method will be described showing how the E. M. F. of a cell may be compared with one whose E. M. F. is known.

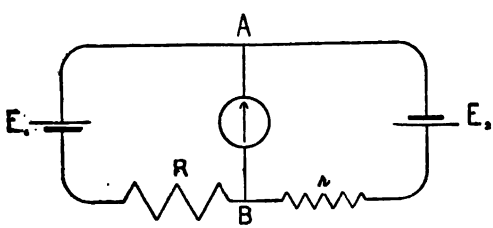


FIG. 8.—Connections for Comparing E. M. F. of Cells.

The two batteries or cells to be compared are joined up as shown in Fig. 8, their opposite poles being connected by leading wires and resistances R and r being inserted in one side of the connections, the points A and B being connected by a galvanometer or the double reading voltmeter. If the resistance R is fixed, then r is adjusted until the voltmeter shows no deflection; or, in other words, A and B are at the same potential. When this condition holds then

$$E_1 : E_2 :: R : r$$

from which the E. M. F. of either cell may be found in terms of the other.

The resistances of the leading wires are supposed to be inap-

preciable and the resistances of the cells small in comparison with R and r, but if not, they must be added to R and r (see Chapter VI).

This method is easily arranged and comparison of cells may be made in a very short time. For all practical purposes, however, the E. M. F. of a cell is sufficiently determined by connecting its terminals to the binding posts of a low-reading portable voltmeter. The small curent flowing from the cell is inappreciable owing to the high resistance of the voltmeter, so that the lost volts in the cell are extremely small and the E. M. F. as measured is very near the total E. M. F. of the cell.

Resistance of Cells.

By the resistance of a cell is meant the resistance it offers to the flow of electricity, measured from terminal to terminal, and is the sum of the resistances of the separate parts that go to make up the internal circuit. It is a physical characteristic depending on the elements of which the electrodes are made, of the exciting fluid, and of the depolarizing substance, solid or liquid. The resistance of the electrodes may be reduced by making them in the form of plates, by which a large surface is exposed to the exciting fluid, and the resistance of the electrolyte may be reduced by shortening the path the current in it has to follow. This is done by bringing the electrodes close together, and in some forms, one electrode entirely surrounds the other. The resistance of liquids is high as compared with metals, and that of gases still higher. The resistance of the gases liberated by the chemical action is the chief cause of polarization in a cell, increasing the resistance to such an extent that the current rapidly falls off. This resistance due to the gases is not properly a part of the cell resistance, and being a variable quantity is not included in the internal resistance.

In one method for measuring battery resistance, the battery is inserted as the fourth arm in the Wheatstone bridge, and its ordinary position is taken by leading wires with a key K in circuit. The principle and application of the bridge will be shown later, it being sufficient at this time to simply state methods and results.

The resistance a should be as low as possible and b high. With the key K open (Fig. 9) current will flow through the galvanometer and a deflection of the needle will occur. If on making and breaking the key K, there is no change in the deflection, the points where the leading wires are connected to the bridge must have the same potential. When this is the case and there is no change in the deflection, the following relation holds:

$$B = \frac{aR}{b}.$$

R should be 1000 ohms if possible, b 10,000 ohms, and then a will usually be less than 20 ohms. b should be adjusted until there is

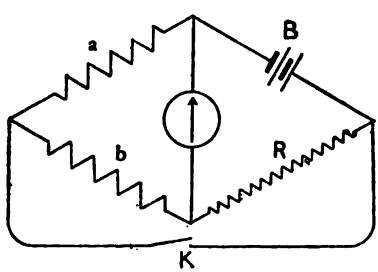


FIG. 9.—Connections for Measuring Resistance of a Cell.

no change in the deflection, but if a change always occurs when the key is opened or closed, determine two values of b, one of which increases, the other decreases the deflection, and take the value which gives the least change.

The galvanometer should be connected between the junction of the two highest and two lowest resistances.

NOTE.—For derivation of the above formula, see Chapter VI.

Resistance of a Working Battery.—When a battery is working through an external resistance and a certain current is being drawn from it, the internal resistance may and will probably be different from its resistance on open circuit, and it is frequently of importance to know what the working resistance is. A sufficiently accurate method for determining this is as follows: With a volt-

meter (see later) measure the difference of potential between the terminals of the battery when on open circuit; call this E_1. Make the same measurement when working through the external resistance and call this E_2, and this should be made before polarization sets in.

When a current is flowing, part of the total E. M. F. is expended in sending current through the external resistance and part through the battery resistance, but only E_2, the fall of potential through the external circuit can be measured, and $E_1 - E_2$ is the fall of potential through the battery; therefore, by Ohm's law, where r is the internal resistance of the battery,

$$C = \frac{E_1 - E_2}{r} \text{ and } C = \frac{E_2}{R},$$

or

$$r = \frac{E_1 - E_2}{E_2} R.$$

If an ammeter (see later) is connected in the circuit, it is not necessary that the value of R should be known, as

$$r = \frac{E_1 - E_2}{C}.$$

When two known resistances are available, r can be calculated as follows: With the resistance R_1 in circuit, measure E_2 and C_1 and with R_2 measure E_2 and C_2, then

$$C_1 = \frac{E_2}{r + R_1} \text{ and } C_2 = \frac{E_2}{r + R_2}$$

and

$$r = \frac{C_2 R_2 - C_1 R_1}{C_1 - C_2}.$$

Grouping of Cells.

Knowing the E. M. F. and internal resistance of the cells with which one has to work, and the character of work to be done, it becomes important to know which is the way to group cells in order to get the best results. It may be that high E. M. F. is desired or a large current, or the greatest current may be wanted, or the most economical working may be sought. There are three

principal ways of arranging cells, namely, in **series**, in **multiple arc** or **parallel**, and in **multiple series**.

Series Grouping.—Cells are connected in **series** when the positive electrode of one is connected with the negative electrode of another, and the positive one of this to the negative of the next and so on, the number so connected being referred to as so many in series. This arrangement is shown in Fig. 10.

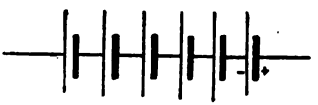


FIG. 10.—Cells in Series.

The effect of such a grouping is to sum up all the electrical and mechanical effects of each cell; that is, the total E. M. F. is the sum of the individual E. M. F's. of each cell, and the total resistance is the sum of the internal resistances of each cell. If the cells have the same characteristics, then this total E. M. F. is the E. M. F. of one multiplied by the number of cells, and the total resistance, that of one multiplied by the number of cells.

By Ohm's law, for a single cell

$$C = \frac{E}{r + R}.$$

Where

C = current in circuit,
E = E. M. F. of the cell,
r = internal resistance of the cell,
R = external resistance in circuit.

With a number of cells m, connected in series,

$$C = \frac{mE}{mr + R}.$$

If there is no external resistance, that is, if the battery terminals are short-circuited, $R = 0$ and

$$C = \frac{mE}{mr} = \frac{E}{r},$$

or the current is no more than if there was one cell with its terminals short-circuited.

If R is very small compared with mr, $C = \frac{E}{r}$, or the current is that of a single cell.

If mr is small compared with R, $C = \frac{mE}{R}$, or in this case the current increases with the number of cells.

Cells connected in series are used on work in which R is already large, so that any increase in the internal resistance is not of much moment, the increased E. M. F. producing increased current.

Multiple Grouping.—Cells are grouped in **multiple arc**, or **parallel**, when all the positive electrodes are connected, and all the negative electrodes connected, or all the positive electrodes are connected to one common conductor and all the negative electrodes to another common conductor. This arrangement is shown in Fig. 11.

The effect of this grouping is to practically make one big cell, for as was shown under the electromotive force of batteries, the difference of potential is due to the electrodes themselves. In the case of the five cells shown, the effect is to make two electrodes each five times as large as that in a single cell and, therefore, the total E. M. F. due to these cells grouped in multiple arc is the same as that due to one cell. In this arrangement, there are now five paths for the current to follow in the battery; or, in other words, the total resistance of these five cells is only one-fifth that of each cell. Or, considering two electrodes each five times as large as that of a single cell, the resistance of each large electrode would be only one-fifth of that of each cell.

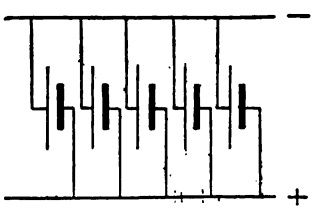


FIG. 11.—Cells in Parallel.

If there are n cells connected in multiple arc, and the resistance of each is r, the total resistance of the n cells is $\frac{r}{n}$, and the total current through the battery, neglecting the external resistance would be

$$C = \frac{E}{\frac{r}{n}} = \frac{nE}{r}.$$

This arrangement, therefore, increases the current, without increase of E. M. F. and is used where a strong current is required with low E. M. F. or for external work in which the resistance itself is low.

Multiple Series Grouping.—Cells are grouped in **multiple series** when some are connected in series, and the groups connected in series are grouped in multiple arc, as shown in Fig. 12.

Here are shown ten cells, groups of two being connected in series and five groups of two in series being connected in multiple arc. The effect of this grouping is to give an E. M. F. double that of one cell, with an internal resistance of one-fifth of the resistance of the two cells in series, or two-fifths the resistance of one cell, assuming they are all alike.

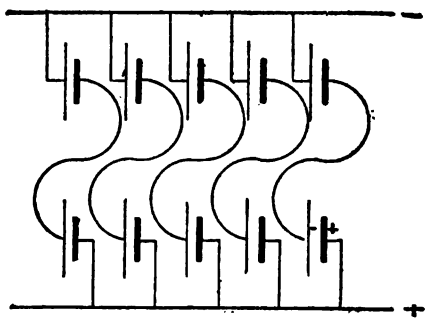


FIG. 12.—Cells in Multiple Series.

In general if there are m cells connected in series and n groups of m cells each connected in multiple arc, the resulting battery current, neglecting external resistance would be given by

$$C = \frac{mE}{\frac{mr}{n}}$$

where C, E, and r have the same significance as before. The total external current through a given resistance R would be

$$C = \frac{mE}{\frac{mr}{n} + R}.$$

It should be noted that the current through each group in series, and consequently through each cell, would be $\frac{C}{n}$.

For most battery work, some modification of this system is used, depending on the difference of potential and current required. It is used also when a higher E. M. F. and stronger current are required than any one cell would give.

Best Arrangement and Efficiency of Batteries.

a. To find the best arrangement of a given number of cells (N) to obtain the maximum current (C) through a given external resistance (R).

In addition to the symbols and significations already used, let

m = the number of cells in series in each group,

n = the number of series groups in multiple.

It can be mathematically shown that the current has its greatest value when the internal resistance of the battery is equal to the external resistance in circuit, that is, when

$$\frac{m \times r}{n} = R.$$

$$\text{Total current} = \frac{\text{total E. M. F.}}{\text{total resistance}}$$

$$C = \frac{mE}{\frac{mr}{n} + R}.$$

Since

$$N = m \times n, \; n = \frac{N}{m} \text{ and } m = \frac{N}{n}.$$

Substituting the value of

$$n = \frac{N}{m} \text{ in } \frac{mr}{n} = R$$

we have

$$\frac{m^2 r}{N} = R \text{ or } m = \left(\frac{NR}{r}\right)^{\frac{1}{2}},$$

and similarly

$$n = \left(\frac{Nr}{R}\right)^{\frac{1}{2}}.$$

This enables us to know how many cells to put in series and how many groups to put in parallel to get the greatest current, R and r being known.

b. To find the greatest current which can be obtained from a given number of cells (N) through a given external resistance (R).

As before

$$C = \frac{mE}{\frac{mr}{n} + R},$$

$$\frac{mr}{n} = \left(\frac{NR}{r}\right)^{\frac{1}{2}} \times \left(\frac{R}{Nr}\right)^{\frac{1}{2}} \times r = R,$$

or

$$C = \frac{\left(\frac{NR}{r}\right)^{\frac{1}{2}} \times E}{2R} = \frac{E}{2}\left(\frac{N}{Rr}\right)^{\frac{1}{2}},$$

an equation in which all the quantities are known to solve for C.

c. To find the number of cells in series (m) and number in **parallel** (n) required to give a current (C) through an external **resistance** (R) and to have an efficiency (F).

By the *efficiency* of a battery is meant the ratio between the total **work available** in the external circuit and the total work developed by **the battery.** The total work developed by the battery is the **product of the** total E. M. F. and total current (see Joule and **Watt), and the** total available work is the product of the total **external current** and the fall of the potential through that circuit.

If e = fall of potential through external circuit

F = efficiency,

then $$F = \frac{eC}{EC} = \frac{e}{E},$$

but $e = CR$ **and** $E = C\left(R + \frac{mr}{n}\right)$.

$$\therefore \quad F = \frac{R}{R + \frac{mr}{n}},$$

or the smaller the internal resistance r, the greater is F.

From

$$F = \frac{R}{R + \frac{mr}{n}},$$

we have

$$\frac{mr}{n} = \frac{R(1-F)}{F},$$

and substituting this value in the equation for current we have

$$C = \frac{mE}{\frac{mr}{n} + R} = \frac{mEF}{R},$$

or

$$m = \frac{CR}{EF} \text{ and } n = \frac{Cr}{E(1-F)}.$$

d. To find the efficiency of a battery arranged (m) in series and (n) **in parallel** through an external resistance (R).

There are always two values for the efficiency (F) for any particular number of cells (N).

$$N = m \times n = \frac{CR}{EF} \times \frac{Cr}{E(1-F)} = \frac{C^2Rr}{E^2F(1-F)}$$

or

$$F = \frac{E(N)^{\frac{1}{2}} \pm (NE^2 - 4C^2Rr)^{\frac{1}{2}}}{2E(N)^{\frac{1}{2}}}.$$

This gives two values for F except when

$$NE^2 = 4C^2Rr.$$

Substituting in this the value of $N = mn$

and

$$C^2 = \frac{m^2E^2F^2}{R}$$

it reduces to

$$4F^2 = R \times \frac{n}{mr}.$$

Now when $R = \frac{mr}{n}$ we have the greatest current, and then

$$4F^2 = 1 \text{ or } F = \tfrac{1}{2} \text{ or } 50 \text{ per cent.}$$

This means that when the cells are so grouped as to cause the greatest current, the battery is doing work at its greatest rate, but it is only working at an efficiency of 50 per cent, or only 50 per cent of the total work is being utilized, the rest being absorbed in the battery itself.

Economical Working.—As far as the cost is concerned the most economical grouping would be that which would give the least consumption of materials, which in most batteries would mean the consumption of the zinc, by the consumption of which the chemical action is kept up.

The weight of zinc used is given by the formula $w = Czt$, where

w = weight in grammes of zinc consumed,
C = current in amperes,
z = electrochemical equivalent of zinc,
t = time in seconds.

w is evidently directly dependent on C, so the most economical working would be when C is the least, which would virtually be the case when the cells are all grouped in series.

Examples of Grouping of Cells.

1. What arrangement of 24 cells, each of E. M. F. 1.3 volts and resistance 2 ohms, will send the greatest current through an external resistance of 13 ohms?

For greatest current, the internal resistance must be equal to the external resistance.

Let m = the number of cells to be grouped in series.

n = the number of series groups to be placed in parallel.

$m \times n$ = whole number of cells.

$\frac{mr}{n}$ = internal resistance, 13 = external resistance,

or

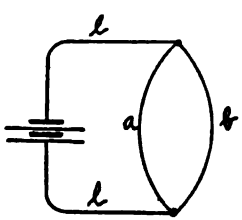
$$\frac{2m}{n} = 13 \qquad mn = 24.$$

$$\therefore \quad m = 12 \qquad n = 2.$$

2. What is the best arrangement to give the greatest current from 12 cells, E. M. F. of each 1.8 volts and resistance 5 ohms. The external resistance consists of an instrument .5 ohm resistance, of the leading wires .25 ohm resistance, and two electrolytic cells, one of 4 ohms resistance and the other of 3 ohms. *Ans.* $m = 4$. $n = 3$.

3. A battery of 40 cells is to be so arranged that it will send the maximum current through an external resistance consisting of two branches, connected to the battery by two leading wires, one of resistance of 2 ohms, the other of 2.5 ohms. One branch has a resistance of 6⅔ ohms and contains 4 fuses in series, each of 1 ohm resistance, and the other has a resistance of 11 ohms and contains 7 fuses in series, each of 3 ohms resistance. *Ans.* $m = 10$. $n = 4$.

4. A circuit is arranged as in the figure. The branch *a* is composed of 10 fuses in series and *b* of 15, each fuse having a resistance of 1 ohm and requiring .75 ampere to fire it. The leading wires have a resistance of 3 ohms. How should a battery of 36 cells, each having an E. M. F. of 1 volt and resistance .25 ohm be arranged to give the maximum current through the fuses? *Ans.* all in series.



5. Twelve cells, each of which has an E. M. F. of 1.9 volts and resistance .28 ohm are to be coupled up so as to develop the greatest possible amount of heat in a copper wire of .21 ohm resistance. How must this be done? *Ans.* No. of groups in parallel, 4.
No. in series in each group, 3.

CHAPTER IV.

TYPES OF PRIMARY BATTERIES.

Batteries for use on board ship are generally confined to one or two classes, the Leclanché type being in general use for call, telephone, and alarm circuits, and some form of dry cell used for firing guns, torpedoes, or mines. The use of cells for bell circuits is gradually being curtailed by the dynamo current and an illustration of how this is accomplished will be given later, but the cells in ordinary use will be described.

Leclanché Cell.

There are several types of this cell to be found, but their general characteristics are the same, differences arising from the manner in which the electrodes and depolarizer are made up, this last making a difference in the resistance of the various types.

The positive electrode, or anode, is zinc, as near chemically pure as possible, and some forms being amalgamated. This is generally in the form of a round strip not unlike a lead pencil in shape. The negative electrode, the kathode, is carbon and in different types, this is made up in different shapes, and it is this difference that makes the various types of this cell. The exciting fluid is ordinary clean water in which is dissolved the chemical salt, ammonium chloride, or the sal ammoniac of commerce. The depolarizer is a paste made of peroxide of manganese, a black powder, mixed with powdered graphite. In the earlier forms, the carbon was imbedded in this paste which after treatment became hard, and the whole filled a porous earthenware cup that stood in the sal ammoniac solution. The porous cup was found to increase the resistance of the cell and another form was adopted. In this the depolarizer is in the form of hard blocks and these are secured to the carbon

plate, one on each side, by rubber bands, and then the whole is placed in the exciting fluid, in which the zinc simply stands.

In another form of this battery, notably in the Samson and Hayden types, the carbon is made in the form of a hollow cylinder and the depolarizer is placed inside the cylinder. The cell is an ordinary glass jar, coated a short distance from the top with paraffin to prevent the salts that are formed from "creeping" over the top, and covered with a hard rubber top, through which the terminals of the electrodes project.

Chemical Action in the Cell.—The action that goes in the cell is represented by the following chemical formula:

$$aC + b(MnO_2) + c(NH_4Cl) + dZn = aC + (b - 2)(MnO_2) + (c-2)(NH_4Cl) + Mn_2O_3 + 2NH_3 + H_2O + ZnCl_2 + (d-1)Zn.$$

The current is primarily produced by the action of the ammonium chloride on the zinc, the zinc gradually wasting away as shown in the formula and the salt zinc chloride being formed. It is the double salt of this chloride that collects on the electrodes and on the sides of the cell and sometimes works its way over the edges of the cell. Free ammonia gas is evolved from the ammonium chloride which escapes or is dissolved in the liquid. Hydrogen is liberated from the ammonium chloride, and this would soon cause depolarization were it not for the manganese peroxide. Under the chemical action, this salt gradually gives up oxygen and part of it is converted into another manganese salt, Mn_2O_3. The oxygen thus liberated unites with the hydrogen freed from the ammonium chloride, to form water, thus getting rid of the chief cause of depolarization. As shown by the formula, the zinc gradually wears away while the carbon remains unchanged.

In one form of this cell, the E. M. F. is about 1.48 volts with an internal resistance of 4 ohms, though these values vary in the different types. It gives a quick current for a short time, but its great advantage lies in the fact that on open circuit it recovers itself so quickly. It runs down quickly owing to the formation of the hydrogen bubbles, but part of the action goes on when the circuit is open, the hydrogen uniting with the oxygen. This quick recovery

makes it particularly useful for bell work, where the current is not steady or continuous but intermittent.

With ordinary care a good Leclanché cell should last for years, and by this is meant keeping the cells clean, free from accumulation of salts on the electrodes, and taking precautions to keep the liquid from splashing over as the ship rolls. The battery locker should be kept free from dust and be in a cool, dry location. Above all, it should be seen that there are no short circuits when the circuit is open, as this would soon destroy the usefulness of any cell.

Sal Ammoniac Solution.—Different classes of cells of the Leclanché type require different strengths of solution to get the best results, but an average solution is about five ounces of dry ammonium chloride (sal ammoniac) to one quart of water. If the solution is too strong the double chlorides of zinc and ammonium are liable to crystallize and be deposited on the zinc, increasing the internal resistance and lowering the E. M. F.

Effect of Double Chlorides.—There is generally more or less of the double chloride of zinc and ammonium present in every sal ammoniac cell. This is heavier than the solution of zinc chloride and ammonium chloride and sinks to the bottom of the cell. Zinc in a zinc chloride solution is positive to zinc in a solution of the double salt, the result of which is a local action which tends to dissolve the zinc at the top and deposit it at the bottom. The cell is practically short-circuited on itself and this explains why almost all zincs in this class of cells grow thinner at the top first. Near the surface there is a slight oxidation process which also tends to thin the zincs.

Firing Batteries.

Different forms of batteries are used for firing guns, illuminating the night sights of guns, and for firing torpedoes and submarine mines. The general form adopted for firing guns and torpedoes is a dry cell similar in its electrical conditions to the Leclanché type. Some forms used are known commercially as "Roach Standard Dry Cell," "O. K. Cells," "Harrison Electrolyte Jelly Cells." The "Dry Cell" is furnished in two sizes, the small dry cell and the large dry cell.

In the dry cell, the cell itself forms the anode, being made of zinc to which is soldered the terminal. The kathode is a carbon slab imbedded in a dry paste which fills the whole cell. Next the zinc cup is a layer of powdered ammonium chloride mixed with lime, inside of which is a powdered mixture of graphite and manganese dioxide in which the carbon is imbedded in the center of the cell. The carbon projects over the top of the cup to which the terminal is secured. After the paste is packed in around the carbon and fills the cell, the whole is sealed with pitch to prevent the access of moisture and for mechanical protection. There is a small hole left in the pitch through which a small amount of water may be added if necessary and to allow the escape of gases.

The E. M. F. of the small cell, dry, is 1.5 volts with an internal resistance of not over .3 ohm, while the large cell has an E. M. F. of 1.5 volts and a resistance of not over .15 ohm.

For firing, the cells are arranged in firing boxes, there being four styles in use, known as "Battery Box Gun Firing," used entirely for firing the primers of the guns; "Battery Box, Combination," used both for firing guns and illuminating the night sights; "Battery Box Torpedo Circuit," and "Battery Box, Submerged Tube," their names signifying their uses. These boxes are of different sizes and shapes, depending on the number of cells to be used, and are made of wood, surrounded by galvanized iron, the whole being made water-tight by a hinged cover.

For testing these batteries firing key-boards containing buzzers are supplied, the circuit tested by ringing the buzzers before connected to the firing circuit on the gun or torpedo. In addition a small bridge of platinum is furnished which should heat when connected to the battery terminals. In firing guns, the circuit is completed through the gun, one terminal of the battery being grounded to the gun, the other connected to the primer. Two means are used for making the circuit, by means of a hand grip which, when squeezed, brings contact points together, and by means of a pistol grip which closes the circuit by pulling the trigger. For firing submerged torpedoes a press key is used. As an additional tester for continuity of circuit a small galvanometer is used.

Common Batteries.

Although the Leclanché type of cell is used almost to the exclusion of all others on shipboard, the following table may be useful as giving the characteristics of some of the standard common cells:

STATISTICS OF CELLS.

Class.	Name.	Anode.	Electrolyte.	Kathode.	Depolarizer.	E.M.F.	Remarks.
Mechanical depolarizer.	Volta.	Zinc.	Sulphuric acid (dilute).	Copper.	None.	.9	Polarizes rapidly.
Same.	Smee.	Zinc.	Sulphuric acid (dilute).	Platinized silver.	None.	1 to .5	Same.
Chemical depolarizer.	Bunsen.	Zinc.	Sulphuric acid (dilute).	Carbon.	Nitric acid.	1.9	Kathode and depolarizer in porous cup.
Same.	Grove.	Zinc.	Sulphuric acid (dilute).	Platinum.	Nitric acid.	1.9	Same.
Same.	Leclanché.	Zinc.	Ammonium chloride.	Carbon.	Peroxide of manganese.	1.48	High resistance about 4 ohms.
Electro-chemical depolarizer.	Daniell.	Zinc.	Zinc sulphate.	Copper.	Copper sulphate with crystals.	1.07	Kathode and depolarizer in porous cup.
Same.	Chloride of mercury.	Zinc.	Ammonium chloride.	Carbon.	Paste of mercurous paste.	1.45	Same. For small currents.
Same.	Chloride of silver.	Zinc.	Ammonium chloride.	Silver.	Silver chloride.	1.08	Used for testing.
Same.	Latimer Clark.	Zinc.	Paste of mercurous sulphate with zinc sulphate.	Mercury.	Electrolyte.	1.442	Standard cell for very small currents.

CHAPTER V.

SECONDARY BATTERIES.

Secondary batteries are combinations of secondary cells, or as they are sometimes called, accumulators or storage cells. A secondary cell is an electrochemical transformer of energy. In a primary cell, the elements are active chemically in themselves and produce electrical energy by chemical decomposition, and when the constituents are entirely decomposed, the cell is dead, and can only be made active again by a fresh supply of its constituents. A secondary cell can be made active by the passage of a current in the opposite direction to that which the cell itself develops.

Typical Secondary Cell.

The principle of the secondary cell may be studied by the action of a current on lead plates immersed in a solution of dilute sulphuric acid. Although these lead plates are identical, one may be considered positive and the other negative, and the one by which the current enters the cell is called the **positive** plate, or **anode,** and the other the **negative** plate, or **kathode.** In its original state, such a combination cannot produce an electric current, for whatever chemical action takes place between one lead plate and the acid is counteracted by the chemical action between the other plate and the acid.

If a current from an outside source is sent through such a combination, in a short time oxygen gas is liberated from the water in the acid solution and appears on the anode and unites chemically with the lead of the plate to form a chemical compound, lead peroxide, PbO_2. Due to this compound, the anode turns a brownish color. Hydrogen gas is also liberated from the water in the acid solution by the passage of the current and collects on the kathode, but no chemical action takes place. The water in the

solution which is thus gradually decomposed slowly disappears and the solution becomes more strongly acid.

On stopping the outside current, the cell is now in a different electrical condition, and in the place of the two original lead plates. there is now one plate of lead peroxide, PbO_2, and one of lead, Pb, in the electrolyte of sulphuric acid, H_2SO_4. This is now capable of acting as a primary cell and generating current by the difference of potential existing between the two plates, increased by the chemical action which will take place if the plates are connected outside the cell. The acid will now act chemically on the plate of lead peroxide, and current will result, and in time, both plates will become of the same chemical composition and the current will cease. This is now a secondary cell and can store up the energy given to it until it is required to be used, and can be revived without using any fresh chemicals, by simply passing a current through it.

Elements of Cells.

Cells proper can be made of glass, metal, wood lined with glass or pitch or celluloid. For stationary work glass is the best, but for movable batteries, other forms are chosen.

The electrolytes used may be alkaline, acid, or neutral, and the materials are very numerous, depending on the plates employed.

The plates may be all metallic, or one set may be of metal and the other of carbon, and in some cases neither are metal.

Planté Cells.

The earliest reversible cells were those of the Planté type, developed by M. Gaston Planté about 1860. They differ only from the typical cell described in that the lead plates are made porous, either by mechanical or chemical means. Some are cast porous, others are built up of lead ribbon, and most of them of different makes are treated with nitric acid before being used in the cell.

The positive and negative plates are identical at the start. They have lugs cast on them to project above the level of the electrolyte so that the plate may be completely immersed. A strip of lead is then soldered to the lugs of those intended to be positives and a

similar strip to those intended to be negatives for one cell. The two sets of plates are then pushed into one another to form a compact block, positive and negative alternately, each plate being insulated from the next one by some non-conductor, as India rubber bands, blocks, vulcanite, etc., but remain joined by the lead strips. Such a block of plates is held together by rubber bands or a wooden frame, and the *section,* as it is called, is ready to be placed in the electrolyte.

A battery of cells is now formed by connecting the cells in series, and the whole is ready for *forming.*

This forming consists in sending an electric current through the cells for a long time, with the result, that, notwithstanding both positive and negative plates start identical in their composition, after a time they alter their chemical composition, and soon become capable of retaining a charge; that is, a good primary battery is obtained with reversible properties.

Frequent reversals are necessary to obtain good capacity and it takes a long time before the maximum capacity is reached, and by that time the plates become rotten. A *reversal* is made by completely discharging the cells through a resistance, then charge again the reverse way, then discharge and again charge, etc.

Although this type of cell has points in its favor, such as the fact that a large charging current or rapid discharge does not much injure the plate, yet it is handicapped by the laborious forming process necessary, and has been superseded by a class of cell known as the **Faure** type.

Faure Cells.

In order to increase the output capacity, and to obviate the long and costly process of making a cell by Planté's method, Faure in 1880 suggested pasting the lead plates with easily reducible oxides of lead.

Cells of this type are therefore known as *pasted* cells. The pasted plate is made in many ways but the result sought in all is the same; that is, to produce a porous leaden or other support carrying paste. The paste is carried in holes of different shapes made in the plates, which are made of porous lead or an alloy of lead, for strength.

The anode or positive plate is usually pasted with a stiff paste of red lead, minium (Pb_3O_4), and sulphuric acid, and the kathode or negative plate is pasted with a mixture of litharge, lead monoxide (PbO), and sulphuric acid. The result of each of these pastes is to really form the plates into lead sulphates ($PbSO_4$). After the plates are pasted they are allowed to harden, and are then built up in sections as previously described.

The cells are now connected in series and a current passed through them for a long time, causing the paste on the positives to become converted into lead peroxide, PbO_2, and the paste on the negatives becomes reduced to finely divided spongy lead.

During the *forming* process, the positives become a plum or chocolate color, while the negatives obtain a yellowish tint on the surface and pale slate color at the edges.

Chemical Action in Forming.

The chemical action that takes place in forming is represented chemically thus:

+ plate	solution		− plate	+ plate	solution	− plate
$PbSO_4$	$+ H_2SO_4 + 2H_2O +$		$PbSO_4$	$= PbO_2$	$+ 3H_2SO_4 +$	$Pb.$
lead sulphate	sulphuric acid	water	lead sulphate	lead peroxide	sulphuric acid	lead spongy

The result of the forming is to convert the $PbSO_4$ on the positive plates to PbO_2, which is thus effected: the SO_4 of each sulphate goes to the electrolyte in exchange for oxygen, O, while the hydrogen, H_2, liberated from the water, H_2O, joins with the SO_4 to form sulphuric acid, H_2SO_4. This is represented as follows in the first stage:

$$PbSO_4 + H_2SO_4 + 2H_2O + PbSO_4 = PbO + 3H_2SO_4 + PbO.$$

In the next stage, another atom of oxygen, O, joins the PbO of the positive plate, making PbO_2, and the liberated hydrogen, H_2, of the H_2O going to the PbO of the negative plate, forming $Pb + H_2O$, and this second stage is thus represented:

$$PbO + 3H_2SO_4 + PbO = PbO_2 + 3H_2SO_4 + Pb.$$

The sulphuric acid gradually gets stronger as the forming increases and its specific gravity consequently increases.

It will be noticed that the electrolyte, sulphuric acid, H_2SO_4, appears to play no part whatever beyond making the water a good conductor, yet if it is not added, the chemical actions are not quite the same.

There is an additional action which goes on during forming or charging, as gas is given off at all periods of the charge, first off the positives only and later off the negatives. This would seem to indicate that water is being decomposed, and that the *O* does not unite with the paste of the positives and that *H* is absorbed or goes into chemical combination with the negatives, until, when the end of the forming approaches, the negatives can absorb no more gas and *H* is given off from these plates.

Charging of Cells.

The operation of charging the cells is that of *forming* as previously described, as far as it relates to the chemical action. When formed or charged, the positive plate has been changed to lead peroxide, PbO_2, and the negative to spongy, metallic lead, *PbO*.

As charging proceeds, the specific gravity of the acid increases, and its conductivity increases, or its resistance diminishes. The original solution should be about a 20 per cent solution of pure acid; that is, the mixture should contain about four parts of water to one of acid, and on fully being charged, the solution will be about a 25 per cent solution. Sulphuric acid is a good conductor and water a bad conductor, so, on charging, as the acid strength increases the resistance decreases. If this were not so, the charging current would grow rapidly less as the end of the charge approached.

A well-charged cell has about half the resistance of a discharged one, due to the greater conductivity of the electrolyte and to the fact that the plates are better conductors when charged.

It has been stated under the operation of forming that gases are given off and the operation is not unlike that of boiling. As the surface of the positive plates becomes changed into lead peroxide, the material to be acted upon by the current grows less and less, and consequently the current is too large to do the work and the water of the electrolyte is decomposed. This can be obviated by

lowering the current, or stopping it altogether for a time and then starting it, when it will be noticed that the boiling does not immediately recommence. Water should be added from time to time to keep the plates well covered, and the specific gravity of the acid should be kept up.

If too large a current is used for the area of the plates, *buckling* is apt to occur, and short circuits in the electrolyte results through the plates touching. Buckling is due to unequal expansion of the plate and as the paste expands on discharge the expansion and contraction should be symmetrical, or the paste is apt to loosen from its supports.

The plates in each cell should be so arranged that the resistance from all parts of one plate to every portion of the adjoining one should be equal, and if not, buckling is apt to take place. All connecting strips should be large and short and the junctions should be clean and tight to reduce the resistance.

Discharging of Cells.

On the discharge of a cell, the reverse chemical action takes place from that on forming or charging. The chemical action is thus represented:

$$PbO_2 + 3H_2SO_4 + Pb = PbSO_4 + H_2SO_4 + 2H_2O + PbSO_4.$$

This shows that the cell returns to its original state and in the meantime has stored up the energy of the charging current. The action also goes on slowly when discharge is not taking place and the cell is idle. The gradual loss of charge is somewhat similar to the local action that goes on in a primary cell. The lead peroxide and the lead decompose the acid, producing $PbSO_4$, and the local action of the positive plate will be more active if there is but a thin coating of the peroxide.

The rate of discharge depends upon the type and size of plate; but the discharging current can be larger than the charging current. There should always remain about 25 per cent of the total charge the cell is capable of taking, and the moment that the E. M. F. falls below an average of 1.8 volts per cell, the battery should be charged. In testing for this, not the whole E. M. F. should be

tested, but each single cell should be tested with a low-reading voltmeter, which should be carefully calibrated, as a small error might make considerable trouble. If in any cell the E. M. F. falls to 1.7 volts or below it needs charging, or if the others are up, this one should be cut out of circuit.

When the plates are nearly discharged nearly all the paste on the positives is in the form of $PbSO_4$ and this will soon decompose into higher sulphates which ruin the plates or cause them to buckle when charging. Too rapid a discharge buckles the plates and very sudden discharges loosens the paste, even though the current may be well within its limit, and current should be drawn slowly from the battery until it reaches the maximum desired. Not more than 25 per cent of the maximum should be suddenly drawn from the plates.

If from any cause, a cell in the battery becomes dead, it should be immediately cut out, for on discharging the current will charge it the wrong way, which will reduce the effective E. M. F. of the battery by twice its voltage as well as soon ruin the cell, due to the formation of sulphates, buckling, and the loss of paste.

Effect of Specific Gravity of Solution on E. M. F.

The E. M. F. of a lead sulphuric acid cell varies with the specific gravity of the acid of a charged cell, but averages about 2 volts per cell. For a variation in voltage for 1.9 to 2.1 volts the specific gravity variation is from 1.05 to 1.3, and between these limits, the variation of voltage is gradual, but outside the limits the voltage varies much more rapidly than the specific gravity.

Capacity and Output.

Practically the only limit to the current which a secondary cell will give is the resistance to which it is connected, as the internal resistance of the cell itself is very low. A short circuit of low resistance may produce such a high current that it may burn the contacts or even the plates, or produce buckling of the plates.

The current that can safely be taken from a cell depends on the type of cell and the total area of the positive plates, counting both

sides, and is rated as so many amperes per square foot, and in different types and makes may vary from 5 to 25 amperes per square foot.

The capacity of a cell is rated in either **ampere hours** or **watt hours,** meaning that the cell can be discharged at a certain rate of current for so many hours, whose product will equal to the output in ampere hours.

Efficiency.—The efficiency is the ratio of output to input and

$$\text{Quantity efficiency} = \frac{\text{ampere hours given out}}{\text{ampere hours put in}}, \text{ and}$$

$$\text{Energy efficiency} = \frac{\text{watt hours given out}}{\text{watt hours put in}}.$$

Types of Secondary Cells.

Many patents have been taken out for secondary cells, but they may be generally classified in three classes:

1. Those in which the active element is formed from the substance of the plate itself.

2. Those in which the active element is formed from some reducible lead salt applied to the plate.

3. Those in which one element of class 1 is employed for one plate and class 2 for the other.

Chloride Secondary Cell.—This type of cell presents some peculiarities in the construction of the plates, chloride of lead being used in the manufacture of the negative plates. The chemical properties of the positive plate resemble the cells of the Planté type, though the mechanical method of construction is different. For purposes of rigidity, an alloy of lead and antimony is run into molds, and these are so constructed that there are round holes in them, closely spaced, each hole tapering from the outside faces towards the center. These holes are filled with rosettes of pure lead, and they are forced under great pressure into the countersunk holes.

The plates are then formed by coupling them alternately with dummy negative plates in sulphuric acid, and passing a current through, when all the interstices of the pure lead rosettes are filled with a fine coating of lead peroxide, PbO_2.

In the manufacture of the negative plates, pellets of lead chloride $PbCl_2$ are first made, and they are assembled on the plate molds, which are provided with pins over which the pellets slip. Molten lead is then run into the molds under pressure. The cast plates containing the pellets of $PbCl_2$ are then placed alternately with zinc plates in a bath containing a solution of $ZnCl_2$ and short-circuited when the following reaction takes place:

$$PbCl_2 + Zn + ZnCl_2 = 2ZnCl_2 + Pb$$

and the pellets become spongy lead.

When they are connected up with the positive plates with sulphuric acid and charged, the hydrogen evolved combines with the last trace of chlorine from the pellets and leaves them pure spongy lead.

The $PbCl_2$ is formed from mixing known quantities of lead oxide, PbO, and acetic acid, $C_2H_4O_2$. From this, acetate of lead is produced which is treated with hydrochloric acid, HCl, and which precipitates all the lead acetate. The solution that is left contains acetic acid and lead chloride, according to the reaction,

$$Pb(C_2H_3O_2)_2 + 2HCl = PbCl_2 + 2C_2H_4O_2.$$

The $C_2H_4O_2$ is separated from the solution by forcing it through a filter press while the $PbCl_2$ is left behind in the form of white paste cakes. This is then dried and mixed with a small percentage of finely divided metallic zinc and this mixture is heated to a very high temperature when it becomes a fluid. This fluid is then poured into molds the shape of the pellets.

Edison Alkaline Cell.—In this cell the positive active material consists of a finely divided high oxide of nickel, and the negative material of finely divided iron with an electrolyte of a solution of potassium hydrate. The active materials are mixed with graphite and molded under pressure into thin cakes. The plates are made of nickel steel, in which are slots for holding the cakes which are also enclosed in thin covering of nickel steel.

On discharge the iron oxides while the nickel oxide is reduced to a lower oxide.

Regulation.

Since the voltage of a cell may vary from about 1.8 volts at the end of discharge to 2.3 volts at the end of charge, a number of cells in series will produce a widely varying voltage unless some regulating means are provided to compensate for the change of voltage.

The simplest method is to use a resistance in the battery circuit but this is objectionable because of the waste of energy.

A common method consists in varying the number of cells in series. On an E volt circuit, the number of required cells is $\frac{E}{1.8}$ at the time of charging and $\frac{E}{2.3}$ when fully charged, and an arrangement must be provided whereby $\frac{E}{1.8} - \frac{E}{2.3}$ may be cut out or switched in, one by one. These cells are called **end cells.** The terminals of these cells are connected to contact points arranged in a circle over which moves a contact arm, which by moving one way or the other acts to raise or lower the total voltage by varying the number of cells in series.

In switching from one point to the next, the circuit must not be opened, nor must the contact arm touch two adjacent contacts as this would short circuit the cell to which these terminals are connected. The end cell switches are provided with an auxiliary contact either on the movable arm or fixed near each main contact. The main and auxiliary contacts are joined by a resistance, and the auxiliary contact rests on one of the switch contacts while the main contact touches the adjoining point. By this means the circuit is not broken, being completed through the resistance which has too low a value to affect the line potential, but is sufficiently great to prevent the cell from being short-circuited.

Series and Parallel Charging.—In the case of most pasted plates as received from the manufacturers, the forming process consists of a long, continuous charge, lasting over a period from 48 to 60 hours, and should continue until the specific gravity of the acid solution shows no increase for several hours, nor the voltage of any cell shows an increase for the same time. The hydrometer is a

better indication of the state of charge than a voltmeter, though both should be used.

When the plates are first placed in the acid solution the specific gravity will fall and a difference of potential of 1.6 to 1.7 volts will be given at the terminals of a cell. At the end of the first charge, each cell should show approximately 2.5 volts and the specific gravity of the solution should attain its original value.

The source of charging voltage must be at least slightly greater than the voltage of the whole battery, calculated on a basis of 2.5 volts per cell. Thus, if a battery of 50 cells is to be charged in series, a source of at least $50 \times 2.5 = 125$ volts must be available. The smaller the difference between the charging voltage and the counter E. M. F. of the battery, the smaller would be the charging current, and consequently the longer time it would require to charge it.

If the source of voltage is not sufficient to give the proper charging current against the counter E. M. F. of the battery, the battery may then be charged in parallel by doubling the charging current. Thus, suppose a 110-volt circuit was available to charge 50 cells and the desired charging current was 10 amperes; the 50 cells could be divided into two groups of 25 each, making a maximum counter E. M. F. of $25 \times 2.5 = 62.5$ volts. On first starting the charge, the counter E. M. F. would be $25 \times 1.7 = 42.5$ volts, and with a 10-ampere current, a resistance of $\frac{110 - 42.5}{20} = 3.37$ ohms would have to be inserted in the charging line; the 20 amperes dividing, so that each half of the battery would take 10 amperes each. As the counter E. M. F. increased, the inserted resistance would have to be reduced to keep the charging current constant. After being charged in parallel, by a proper arrangement of switches, the battery can be discharged in series, and the full potential utilized. After charging, the voltage of each cell will fall to a little over 2 volts on open circuit, and on closed circuit will fall very nearly to 2 volts. As discharge takes place the specific gravity of the solution will fall and on a lower limit, the battery should be recharged.

If a 220-volt circuit was available, the battery could be charged in series, and would require $\frac{220 - 125}{10} = 8.5$ ohms in the line.

Boosters.—If the source of voltage is not sufficiently high to overcome the counter E. M. F. of the battery and it is not desired to charge in parallel, other means must be used to help the charging voltage, and machines for doing this are called **boosters.**

An ordinary form of booster for this purpose consists of a shunt generator with its voltage regulated by its field regulator. This may be run by any means available, preferably by a motor, and so arranged in the circuit of the charging source as to add its voltage to that of the charging current. By varying the field of this booster generator, the charging current can be kept approximately constant.

Faults and Remedies.

Nearly all the troubles of storage batteries may be traced either to buckling of plates or bad forms of sulphating, and these are due to want of care either in charging or discharging. Cells that are to remain for a long time without use should be thoroughly charged, and from time to time, be recharged to keep them to the full voltage. This is to prevent the plates from sulphating due to local action and slow leakage due to bad insulation. The color of the plates will at once indicate sulphating as the positive plates instead of being a dark chocolate color will turn grayish all over or in patches, and if there is not a marked difference in the color of the positive and negative plates, something is wrong. Sulphating causes scaling of the plates, falling of the paste, and consequent buckling and short-circuiting.

Bad insulation is a frequent source of leaks, and the shelves on which the cells rest should be kept perfectly dry and the glass cells should rest on wooden bases supported by insulators.

If sulphating has occurred, the white patches should be removed or else the paste is apt to fall out and they should be scraped off and if very bad the sections should be lifted from the cells, taken apart and thoroughly cleaned, and the cell itself cleaned of any deposit that may have fallen in it. Before removing a section, the electrolyte should be drawn off to prevent any danger of short circuits.

Buckling may arise from too high a charging or discharging rate

and often arises from loose paste sticking between plates causing unequal resistance and unequal expansion and contraction. Sometimes plugs of paste fall out and this can happen without being noticed, though it usually follows a sudden large discharge.

The plates should never touch the bottom of the cells and a slight quantity of powder is usually found at the bottom, due to the white sulphate formed on the first chargings.

In charging the greatest care must be observed to see that the leads of the charging circuit are properly connected, and the polarity should always be noted before charging commences. If connections are wrong, the plates throughout the battery become reversed, and the negatives become brown and the positives slate color. There is only one remedy for such a fault, and the cells must be discharged through a resistance but not so that the maximum discharge is exceeded. When the battery shows no E. M. F. or a very low value the leads can be joined up correctly and the charging current started very slowly at first, as there is now very little counter E. M. F. till the cells are charged up the right way. In doing this it is well to vary the current by an adjustable resistance and gradually allow the current to increase.

When the plates are sulphated, the internal resistance is greater and consequently the E. M. F. is much lower. In charging, if all plates are in good condition, they should be charged until they boil, but if the capacity of the cell has been reduced by sulphating, the boiling will occur too soon. This arises from the charging current being too great, as much of the counter E. M. F. has been removed. If boiling does not occur at all, the paste may have fallen from the plates.

If a cell gives no E. M. F. from any cause except complete short circuit, the discharging current has the effect of charging the cell the wrong way. In discharging such a cell it should be disconnected, and connected when charging and in time it may regain its original E. M. F.

CHAPTER VI.

OHM'S LAW AND ITS APPLICATION TO SIMPLE AND DIVIDED CIRCUITS.

Ohm's law may be stated as follows: **The current which flows in a circuit is directly proportional to the difference of potential between the ends of the circuit, and inversely proportional to the resistance of the circuit across which the difference of potential is measured.**

In symbols, the law is expressed thus:

$$C = \frac{E}{R}, \qquad (1)$$

where C = current in amperes,

E = difference of potential in volts,

and R = resistance in ohms.

From (1) also $E = CR$, which expression affords a convenient way of expressing the law; that *the difference, or fall of potential between two points is equal to the current flowing between the two points, multiplied by the resistance between the two points.*

Problems on Ohm's Law.

1. An arc lamp requires a current of 8 amperes at a difference of potential of 44 volts. What will be the value of an external resistance placed in series with the lamp to produce this voltage on a 100 volt main?

The fall of potential through resistance must be $100 - 44 = 56$ volts, and as 8 amperes flows through this resistance, the resistance must be

$$R = \frac{E}{C} = \frac{56}{8} = 7 \text{ ohms.}$$

2. An electric heater is connected by means of a cable to constant potential mains. When 4 amperes are flowing in the circuit the difference of potential across the heater is 98 volts, and when 6.5 amperes are flowing, it falls to 93 volts. Find the resistance of the cable.

If x = resistance of cable, $4x$ is the drop of potential in the cable and $98 + 4x$ = potential of the mains.

Similarly $93 + 6.5x$ = potential of the mains,

or $98 + 4x = 93 + 6.5x$,

or $x = 2$ ohms.

3. A number of 100 volt incandescent lamps are connected at the end of a pair of mains connected to a dynamo. If the resistance of each main is .37 ohm, and the current is 14.6 amperes, what voltage must the dynamo produce at its terminals?

Resistance of cables = $2 \times .37 = .74$ ohm.
Drop in cables = $.74 \times 14.6 = 10.8$ volts.
Potential at dynamo = $100 + 10.8 = 110.8$ volts.

4. The resistance of the filament of an incandescent lamp when cold is 220 ohms. If this value decreases 35% when hot, what current will a pressure of 110 volts send through the filament?

5. A resistance of 20 ohms, on being added to a certain circuit caused the current flowing to be reduced from 13 to 9 amperes. What was the original resistance of the circuit?

6. An ammeter connected in series with a standard resistance of .1 ohm indicates a current of 23 amperes. The difference of potential across the standard resistance is found to be 2.28 volts. Determine the error in the ammeter reading.

7. One end (A) of a wire ABC is connected to earth, the other end (C) is kept at a constant potential of 100 volts. If the resistance of the portion AB is 9.6 ohms and that of BC 2.4 ohms, what current will flow along the wire and what will be the potential at the point B?

Ans. 8⅓ amperes.
80 volts.

8. A primary cell, E. M. F. 1.8 volts, and a secondary cell are connected up in opposition with a resistance of 400 ohms and the strength of the current is observed. On rearranging the cells to send currents in the same direction, it is found that the resistance has to be increased to 4000 ohms in order to reduce the current to its former value. Neglecting the resistance of the cells, find the E. M. F. of the secondary cell, and the current produced.

Ans. E. M. F. = 2.2 volts.
Current = .001 ampere.

Simple Circuits.

So far only the difference of potential between two points with the relation existing between that difference of potential and the current and resistance have been considered. The next step is to consider the total E. M. F. in a circuit and the relation between E. M. F. current and resistance.

In considering the total E. M. F. Ohm's law may be thus stated: **The current produced by a source of E. M. F. is dependent directly on the E. M. F. and inversely on the resistance.**

In symbols as before

$$C = \frac{E}{R}$$

where E = total E. M. F.

This means that the total current flowing through every point in a simple circuit depends directly on the *total* E. M. F. and inversely on the *total* resistance in circuit. The fall of potential around the whole circuit is equal to the total E. M. F. or the difference or sum of the individual E. M. F's., and is also equal to the sum of all the differences of potential from one point to another continuously around the circuit.

By a **simple circuit** is meant one in which the current follows but one path both in its internal and external parts. In other words, it is a circuit in which everything that goes to make up the circuit is in series with each other. The circuit may be made up of cells, leading wires, instruments of different kinds or any electrical apparatus, provided that everything is connected so that the same current traverses every portion of the circuit.

Fig. 13 represents a typical simple circuit; the battery B composed of four cells in series, an instrument G, a resistance R_1, and an electrolytic cell C_1, all in series. The same current will traverse every part of this circuit including the connecting wires 1-2, 3-4, etc.

If E represents the total E. M. F. of the four cells and C the current, r' the resistance of all the connecting and leading wires, and r the total internal battery resistance, then

$$C = \frac{E}{r + r' + G + R_1 + C_1}, \qquad \text{(a)}$$

G, R_1, and C_1 representing the resistances of the parts so lettered.

The fall of potential from 1 to 2 $= C \times$ resistance of $1 - 2$
" " " " 3 to 4 $= C \times$ " " $3 - 4$, etc.
" " " through $C_1 = C \times C_1$
" " " " $R_1 = C \times R_1$
" " " " $G = C \times G$
" " " " the battery $= C \times r$.

The fall of potential all around the circuit from 1 around again to 1 is,

$$Cr' + CC_1 + CR_1 + CG + Cr,$$

and this must equal E, the total E. M. F. of the battery; this corresponding to equation (a).

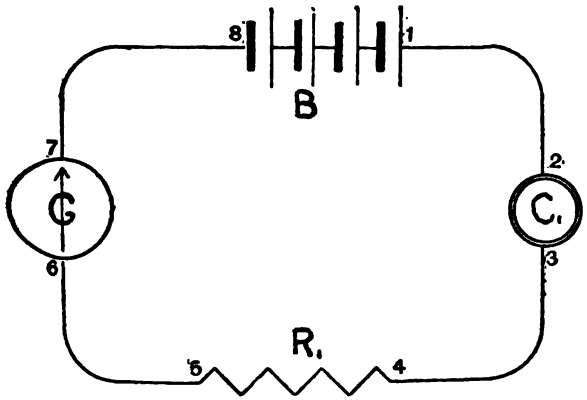


FIG. 13.—Simple Typical Circuit.

Problems as Applied to Simple Circuits.

1. A circuit consists of a dynamo of .5 ohm resistance and four separate resistances of 2, 6, 20, and 1.5 ohms respectively. If the total E. M. F. of the dynamo is 120 volts, find the value of the current flowing and the drop or fall of potential in each resistance.

$$C = \frac{E}{R} = \frac{120}{.5 + 2 + 6 + 20 + 1.5} = 4 \text{ amperes.}$$

Drop in separate parts =

$$\begin{aligned} 4 \times 2 &= 8 \text{ volts.} \\ 4 \times 6 &= 24 \text{ "} \\ 4 \times 20 &= 80 \text{ "} \\ 4 \times 1.5 &= 6 \text{ "} \\ 4 \times .5 &= 2 \text{ "} \end{aligned}$$

Total drop = total E = 120 volts.

2. A battery produces a difference of potential at its terminals of 1.8 volts when sending a current of 2.2 amperes through an external resistance. Assuming the internal resistance of the battery to be .74 ohm, what is the total E. M. F. of the battery?

The fall of potential through battery, or lost volts

$$2.2 \times .74 = 1.63 \text{ volts.}$$

$$\text{Total E. M. F.} = 1.8 + 1.63 = 3.43 \text{ volts.}$$

3. A battery of 20 similar secondary cells sends a current of 6 amperes through the coils of an electromagnet having a resistance of 4 ohms. Determine the internal resistance of each cell, assuming each to have an E. M. F. of 2 volts.

$$C = \frac{E}{R} = \frac{40}{r' + 4} = 6$$

$$6r' = 16 \quad r' = 2.7$$

$$r' \text{ each} = \frac{2.7}{20} = .135 \text{ ohm},$$

or the drop in potential through electromagnet $= 6 \times 4 = 24$ volts.
$\therefore$ drop in battery $= 40 - 24 = 16$ volts,

or $$r' = \frac{16}{6} = 2.7.$$

Counter E. M. F. in a Circuit.—If there are one or more sources of E. M. F. in a circuit, the total is either the sum or the difference of the individual E. M. F's. Where one E. M. F. acts against the source of supply it is said to be a counter E. M. F. and one of the best examples of this counter E. M. F. in a circuit is that of a battery of secondary cells being charged from a dynamo. The E. M. F. of the battery acts against the E. M. F. of the dynamo, and current will only flow from the dynamo if its E. M. F. is the greater. Having found the E. M. F. required to exactly balance the counter E. M. F. of a battery, the additional E. M. F. required to send a charging current through the battery may be found by multiplying the total resistance of the battery by the current required.

Problems on Counter E. M. F.

1. A battery of 50 secondary cells is to be charged from a 125-volt mains, the current not to exceed 15 amperes. Assuming each cell to have an E. M. F. of 1.8 volts and an internal resistance of .004 ohm: determine the value of a resistance that will have to be put in series to accomplish the desired result.

Counter E. M. F. of battery	$= 50 \times 1.8$	$= 90$ volts.
Total internal resist.	$= 50 \times .004$	$= .2$ ohm.
Additional E. M. F. to force 15 amperes through battery	$= 15 \times .2$	$= 3$ volts.
Total E. M. F. required at terminals	$= 90 + 3$	$= 93$ volts.
Drop of potential in resistance	$= 125 - 93$	$= 32$ volts.
$\therefore$ resistance $= \frac{32}{15}$	$= 2.13$ ohms.	

2. Two cells of E. M. F. 1.8 volts and 1.08 respectively are placed in a certain circuit in opposition. The current is found to be .4 ampere. What current will be produced if the cells are properly placed in series.

$$C = \frac{E}{R} \text{ or } .4 = \frac{1.8 - 1.08}{R}$$

$$R = 1.8 \qquad C' = \frac{1.8 + 1.08}{1.8} = 1.6 \text{ amperes.}$$

3. A battery of 50 storage cells is connected up with 5 connected the wrong way. Assuming the E. M. F. and internal resistance of each cell to be respectively 2 volts and .02 ohm, determine what voltage lamps in circuit would get (1) with the faulty connection (2) if they were connected up properly. Resistance of leading wires to lamps .2 ohm and of the lamps 4 ohms. *Ans.* (1) 68.9 volts.
(2) 76.9 volts.

Divided Circuits.

By a **divided circuit** is meant one in which the current does not follow one continuous path from the source of E. M. F., to its return, but rather two or more paths either in its external or internal parts, or both.

In order that the currents in the separate branches that go to make up a divided circuit may be calculated, it is necessary to know the resistances of the separate continuous branches that make up the whole circuit, and it is important to know what the joint resistance of two or more branch circuits may be.

Joint Resistance and Conductivity.

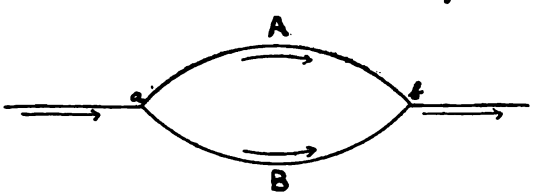


FIG. 14.—Resistances in Parallel.

If *A* and *B*, Fig. 14, are two conductors joined at *a* and *b*, it is required to know the joint resistance, or total resistance of *A* and *B*. These two conductors offer two paths for the flow of current, so the sum of the currents in *A* and *B* must equal the total current flowing from *a* towards *b*.

Conductivity represents the conducting property of conductors, and the joint conductivity from a to b, is the sum of the conductivities of A and B. The greater the conducting power of a conductor, the less the resistance must be; or, in other words, the resistance is the reciprocal of the conductivity.

Let

C_A = current in branch A,
C_B = " " " B,
R_A = resistance of branch A,
R_B = " " " B.

Then the conductivity of A and $B = \frac{1}{R_A} + \frac{1}{R_B} = \frac{R_A + R_B}{R_A R_B}$

and, therefore, the joint resistance of A and $B = \frac{1}{\frac{R_A + R_B}{R_A R_B}}$,

or $$\frac{R_A R_B}{R_A + R_B}.$$

If there was a third branch C, with resistance R_C the joint resistance would be $\frac{1}{\frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C}} = \frac{R_A R_B R_C}{R_A R_B + R_A R_C + R_B R_C}$.

If e is the difference of potential between a and b, by Ohm's law

$$e = C_A R_A = C_B R_B,$$

or

$$C_A : C_B :: R_B : R_A,$$

and

$$C_A + C_B : C_A :: R_A + R_B : R_B,$$

or

$$C_A = \frac{R_B}{R_A + R_B} C, \text{ where } C = C_A + C_B$$

and similarly $C_B = \frac{R_A}{R_A + R_B} C$.

By substituting in C_A its value from $e = C_A R_A$ it follows that

$$\frac{e}{R_A} = \frac{R_B}{R_A + R_B} C,$$

or

$$e = \frac{R_A R_B}{R_A + R_B} C.$$

This shows that the fall of potential e from a to b is equal first, to the current in one branch multiplied by the resistance of that branch, and the same for the other branch, and it is also equal to the total current in both branches C, multiplied by the total resistance of both branches, $\frac{R_A R_B}{R_A + R_B}$.

Laws of Divided Circuits—Kirchoff's Laws.

A consideration of the above facts leads to two laws by which all problems connected with divided circuits may be solved.

a. The algebraic sum of all the currents meeting in a point is zero, that is, the sum of all the currents flowing towards a point is equal to the sum of all those flowing away from it.

b. The total E. M. F. or fall of potential around any one closed circuit is equal to the sum of the products of the current from one point to another by the resistance of the conductor between the same points taken consecutively around the circuit.

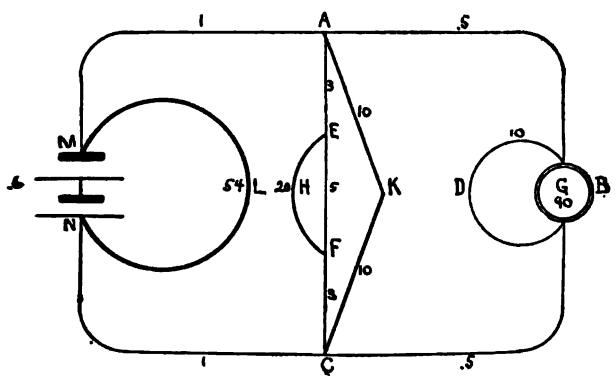


FIG. 15.—Illustration of Divided Circuits.

The application of divided circuits finds continual use in the practical arranging of batteries and outside circuits for firing primers, torpedoes, and defense mines, and also in calculations for determining the different efficiencies of dynamos and motors, all of which will be explained later by practical examples.

Illustration of Divided Circuits.

As an illustration of the method used in solving problems involving divided circuits, the following is given:

Given a divided circuit as shown in Fig. 15, the resistances being marked on the several branches. Given the current in the branch ABC as .72 ampere, find the total battery current and the total E. M. F. of the battery.

Joint resistance of G and $D = \frac{90 \times 10}{90 + 10} = 9.$

Resistance of $ABC = 9 + .5 + .5 = 10$

" " EF and $H = \frac{5 \times 20}{5 + 20} = 4$

" " $AEFC = 4 + 3 + 3 = 10$

" " $AEFC$ and K and $ABC = \frac{10 \times 20 \times 10}{10 \times 20 + 10 \times 10 + 20 \times 10} = 4$

" " $MABCN = 4 + 1 + 1 = 6$

" " $MABCN$ and $L = \frac{6 \times 54}{6 + 54} = 5.4.$

Total resistance in circuit $= 5.4 + .6 = 6.$

Difference of potential between AC = current in $ABC \times$ res. $ABC = .72 \times 10 = 7.2$

Current in $AEFC$ = difference of potential between AC $\div$ resistance $AEFC = \frac{7.2}{10} = .72$

Current in AKC = difference of potential between $AC \div$ resistance $AKC = \frac{7.2}{20} = .36.$

Total current flowing in MA and $NC = .72 + .72 + .36 = 1.8.$

Difference of potential between M and N = current in $MABCN \times$ resistance $MABCN = 1.8 \times 6 = 10.8$

Current in L = difference of potential between M and $N \div$ resistance $L = \frac{10.8}{54} = .2.$

Total current flowing in battery = current in $MABCN$ + current in $L = 1.8 + .2 = 2$ amperes.

Total difference of potential or E. M. F. = total current $\times$ total resistance $= 2 \times 6 = 12$ volts.

Shunts and Compensating Resistances.

In making certain electrical measurements it is necessary that either all or a fraction of the current in the circuit be conducted through the measuring instruments. If currents are large, it is frequently not feasible to allow all the current to pass through the instruments, partly on account of the mechanical objections but generally on account of the delicate construction of the instruments which would be ruined by excessive current. In such cases, it is usual to employ a resistance called a **shunt**, which is placed in parallel with the instrument, and of such a resistance that most of the current will pass through it and only a small fraction through the instrument.

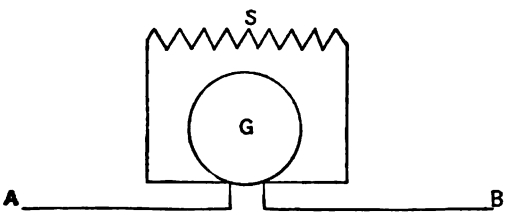


FIG. 16.—Illustrating Use of Shunts.

In Fig. 16 is represented an instrument G in series with an electrical circuit AB and shunted by the resistance S, called the **shunt**.

This is a case of divided circuits, in which the current in AB divides, part flowing through G and part through S.

If C = the total current
C_G = current through G
C_S = " " S,

then $C = C_G + C_S$.

If G = resistance of the instrument
S = " " shunt,

then by the first application of Ohm's law

$$C_G G = C_S S,$$

and

$$\therefore C = \left(\frac{G}{S} + 1\right) C_G. \qquad (1)$$

The factor $\left(\frac{G}{S}+1\right)$ is called the **multiplier,** being the factor by which the current in G must be multiplied in order to find the total current.

To find the currents in G and S, we have from (1)

$$C_g = \left(\frac{S}{G+S}\right) C,$$

and it can similarly be shown that

$$C_s = \left(\frac{G}{G+S}\right) C.$$

Compensating Resistances.—The addition of a shunt to reduce the current flowing through an instrument results in making two paths for the current to flow and consequently the resistance is decreased and the current increased over its original value. In order to reduce the current to the original value, resistances, called **compensating resistances,** are placed in series with the current.

Problems on Shunts and Compensating Resistances.

1. A galvanometer having a resistance of 18 ohms is shunted by a resistance of 2 ohms. Calculate the value of the multiplying power of the shunt, and the compensating resistance.

$$M = \frac{G}{S}+1 = \frac{18}{2}+1 = 10.$$

The original current $C' = \frac{E}{18}$ and $C = \frac{E}{\frac{36}{20}}$.

To reduce C to C' an additional resistance r must be introduced such that

$$C' = \frac{E}{r+\frac{36}{20}},$$

or

$$18 = r + \frac{36}{20} \text{ or } r = 16.2 \text{ ohms.}$$

2. A certain galvanometer of 4 ohms resistance requires a current of .01 ampere to produce a full scale deflection. Calculate the resistance of a shunt which, when used in conjunction with the galvanometer, will give a full scale deflection for 100 amperes. What resistance must be inserted in series with the galvanometer in order that a full scale deflection may be obtained for 100 volts.

$$C = \left(\frac{G}{S}+1\right) G_G$$

$$100 = \left(\frac{4}{S}+1\right).01 \qquad S = .0004 \text{ ohm.}$$

If the fall of potential through galvanometer is to be 100 volts and current .01 ampere, the resistance is

$$R = \frac{E}{C} = \frac{100}{.01} = 10000,$$

or $10000 - 4 = 9996$ ohms must be added.

3. A millivolt-meter with 100 scale divisions has a resistance of 1.5 ohms. Calculate the resistance to be put in series with the instrument in order that the full scale deflection shall represent 100 volts; also calculate the resistance of a shunt in order that the full scale deflection shall represent 10 amperes.

One hundred scale divisions will represent $100 \times \frac{1}{1000} = \frac{1}{10}$ volt or with this voltage and resistance 1.5 ohms, the current through volt-meter is

$$C_G = \frac{\frac{1}{10}}{1.5} = \frac{1}{15} \text{ ampere.}$$

To represent 100 volts at the terminals, the total resistance must be

$$R = \frac{E}{C} = \frac{100}{\frac{1}{15}} = 1500 \text{ ohms}$$

and the added resistance $1500 - 1.5 = 1498.5$ ohms.

$$C = \left(\frac{G}{S} + 1\right) C_G \quad \text{or } 10 = \left(\frac{1.5}{S} + 1\right)\frac{1}{15}.$$

$\therefore\ S = .01007$ ohm.

4. When measuring the value of a certain resistance, the volt-meter was connected up so as to measure the voltage, not only across the resistance, but also across the ammeter. The resistance of the volt-meter was 200 ohms, and of the ammeter .005 ohm. The ammeter reading was 25 amperes, and the volt-meter reading was 4.8 volts. Calculate the true value of the resistance. *Ans.* .187 ohm.

Problems as Applied to Divided Circuits.

1. The torpedo circuits (figure 17) *A* and *B*, are connected by a battery of E. M. F. of 17.5 volts and a total resistance of 3 ohms. The leading wires *C*, *D*, *A*, and *B* have a resistance of 1 ohm each. In *A* are 4 fuses in series. How many in series in *B* can be inserted, so that all will ignite simultaneously? Each fuse has a resistance of .5 ohm and requires .5 ampere to ignite it.

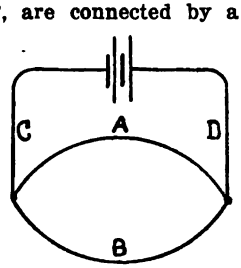


FIG. 17.

To insure ignition it must be assumed that .5 ampere flows in *B*, for *A*'s resistance being less, there will be more than .5 ampere in that

branch, and how much more flows in that branch is a matter of indifference, as if each branch has .5 ampere or over, the fuses will all ignite together.

x = No. of fuses required,
C = Current in battery,
C_A = " " branch A,
C_B = " " " B,

then $17.5 = 3 \times C + C \times 1 + (4 \times .5 + 1)\ C_A + C \times 1$,

$17.5 = 3 \times C + C \times 1 + (x \times .5 + 1)\ .5 + C \times 1$,

$C = C_A + C_B \qquad C_A + .5 = C$

$17.5 = 5C_A + 2.5 + 3C_A \qquad$ or $C_A = \frac{15}{8}$

$3C_A = (.5x + 1)\ .5, \qquad$ or $x = 4 \times \frac{41}{8} = 20.$

2. A battery (figure 18) of 15 volts E. M. F. and 6 ohms resistance has its poles connected by three circuits in multiple arc. Two of these contain fuses and their resistances with the fuses are 2 and 3 ohms respectively. What is the greatest resistance that can be given the third circuit without igniting the fuses, if ½ ampere be required to ignite a fuse?

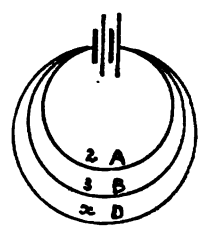


FIG. 18.

The current of ½ ampere must be in the circuit of smallest resistance. Solve as preceding problem. *Ans.* $x = \frac{2}{3}$ ohm.

3. With a constant E. M. F. of 5 volts at E (figure 19), what is the current through h, a, b, and c, the resistance of the parts FhG, FaG, FbG, and FcG being 8, 4, 3, and 6 ohms respectively?

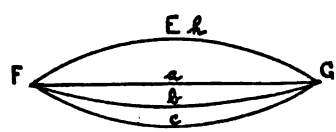


FIG. 19.

$5 = 8C_h + 4C_a,$
$4C_a = 3C_b = 6C_c,$
$C_h = C_a + C_b + C_c,$

or $\quad 5 = 8C_a + \frac{8 \times 4C_a}{3} + \frac{8 \times 4C_a}{6} + 4C_a \qquad$ or $C_a = .1785$ amp.

$C_b = \frac{4}{3} C_a = .238 \qquad C_c = \frac{4}{6} \times C_a = .119,$

$C_h = .1785 + .238 + .119 = .5355,$

or the total external resistance $= \frac{1}{\frac{1}{4} + \frac{1}{3} + \frac{1}{6}} = \frac{12}{9}$

$$C_h = \frac{5}{8 + \frac{12}{9}} = \frac{45}{84} = .5356 \text{ as before.}$$

4. A battery of 4 cells is arranged as in the diagram (figure 20). Required, the current through the battery and the wire E, and the difference of potential between B and C. The E. M. F. of each cell is

1.8 volts, resistance of each cell .5 ohm, resistance of $AB = 2$ ohms, of $CD = 3$ ohms, $E = 4$ ohms, $F = 6$ ohms, $G = 7$ ohms.

If the wire G were cut, would the current through the battery be increased or decreased; would it be increased or decreased through E?

Total $R = 4 \times .5 + 2 + 3,$

$$+ \frac{4 \times 6 \times 7}{4 \times 6 + 4 \times 7 + 6 \times 7}$$

$$C = \frac{E}{R} = \frac{4 \times 1.8}{R}$$

$= .819$ ampere through battery,

$4C_E = E - 2C - 2C - 3C,$

$= 7.2 - 5.733 = 1.467,$

$$C_E = \frac{1.467}{4} = .366.$$

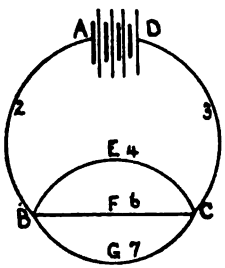


FIG. 20.

If G were cut, the resistance would be increased, and the battery current would be decreased.

Difference of potential between B and $C = 4C_E = 1.467$.

$4C_E = E - 7C$. Now if C is decreased, $4C_E$ is increased and that being the difference of potential between B and C the current through E would be increased.

5. The interpolar portion of a voltaic circuit consists of three separate wires in multiple arc, their resistances being 30, 50, and 70 ohms. If the E. M. F. of the battery is 5 volts and internal resistance 6 ohms, find the current in battery and through wire of greatest resistance.

Ans. Battery current .24 ampere.

Current through greatest resistance .0508 ampere.

6. Suppose a battery and wires connected as in the diagram, figure 21.

Resistance of $ADB = 50$ ohms, $ACB = 30$ ohms and EB an unknown resistance. A volt-meter connected at E and B shows the same reading as when connected at A and C. The resistance of AC being ⅛ of ACB, find the resistance of EB.

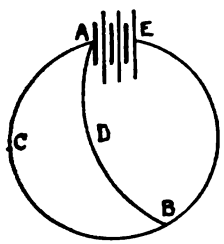


FIG. 21.

$$e_{A.C} = \frac{30}{8} \times C_{A.C} = x \times C_{EB}$$

$x =$ unknown resistance

$$50 \times C_{AB} = 30 \times C_{AC} \qquad C = C_{AB} + C_{AC}$$

$$C_{AB} = \frac{3}{5} C_{AC}.$$

$$\therefore \quad C_{EB} = \frac{3}{5} C_{AC} + C_{AC} = \frac{8}{5} C_{AC}$$

$$\frac{10 \times C_{AC}}{C_{EB}} = x,$$

or $$x = \frac{10 \times C_{AC}}{\frac{8}{5} \times C_{AC}} = 6.25 \text{ ohms.}$$

7. Three parallel circuits contain 14, 10, and 4 torpedoes respectively and resistance of leading wires in each circuit is 1 ohm. What is the smallest number of cells (E. M. F. of each 1 volt and internal resistance of each .6 ohm) required to explode all the torpedoes simultaneously and how must the cells be arranged? Resistance of each fuse .5 ohm and requires 1 ampere to fire it.

Assumption necessary: that the current in the greatest resistance must = 1 ampere. *Ans.* 96 cells required; 6 groups in parallel, and 16 cells in series in each group.

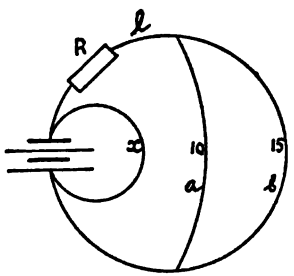


FIG. 22.

8. Taking problem 4 under grouping of cells, what resistance added to l will prevent the firing of the fuses? Find the greatest resistance which, used a shunt between the poles of the battery, will prevent firing (figure 22).

Solution of the problem mentioned shows that the battery should be composed of 36 cells, all in series.

If in a there is anything less than ¾ ampere, the fuses will not fire in that branch, and in b the resistance being greater than in a, they will not fire. If there is just ¾ ampere in a, we have $10C_a = 15C_b$, or $C_b = \frac{10}{15} \times \frac{3}{4} = \frac{1}{2}$ ampere, or the whole current must be $\frac{3}{4} + \frac{1}{2} = \frac{5}{4}$ ampere.

The problem now becomes, what resistance R added in series in the main circuit will make the battery current $= \frac{5}{4}$ ampere.

$$C \text{ total} = \frac{E \text{ total}}{R \text{ total}}, \qquad \text{or} \quad \frac{36}{36 \times \frac{1}{4} + R + \text{ext. res.}} = \frac{5}{4};$$

$$\text{ext. resist.} = 3 + \frac{10 \times 15}{10 + 15} = 9 \text{ or } 5R = 36 \times 4 - 90,$$

$$R = 10.8 \text{ ohms.}$$

¼ ampere must be the least current in the external (fuse) circuit in order that the fuses will not fire.

$$\text{Total external resistance} = \frac{9x}{9 + x},$$

or $$C \times \frac{9x}{9 + x} = 9 \times \text{fuse current or } C \text{ total} = \frac{5\,(9 + x)}{4x}$$

$$C \text{ total} = \frac{E \text{ total}}{R \text{ total}} = \frac{36}{9 + \frac{9x}{9 + x}} = \frac{5\,(9 + x)}{4x}.$$

or $$\frac{36 \times 4x \times (9 + x)}{81 + 18x} = 5\,(9 + x) \qquad x = 7.5 \text{ ohms.}$$

Illustration of Formula

Application of Kirchoff's Laws—Derivation of for Comparing E. M. F. of Cells and for Finding Resistance of a Cell.

(See Chapter III.)

By Kirchoff's laws, Fig. 23,

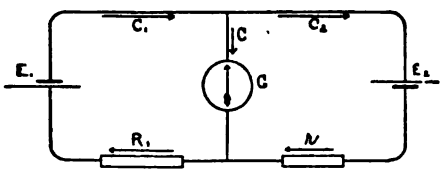


FIG. 23.—Connections for Comparing E. M. F. of Cells.

$$C_1 = C + C_2, \tag{1}$$
$$E_1 = C_1R_1 + CG, \tag{2}$$
$$E_2 = C_2r - CG, \tag{3}$$

substituting the value of C_1 in (1), in (2)

$$E_1 = CR_1 + C_2R_1 + CG,$$

from (3)

$$C_2 = \frac{CG + E_2}{r},$$

or

$$E_1r = CR_1r + CGR_1 + R_1E_2 + CGr$$

and

$$C = \frac{E_1r - E_2R_1}{R_1r + GR_1 + Gr};$$

when the balance is established $C = 0$, or

$$E_1r - E_2R_1 = 0,$$

or

$$\frac{E_1}{E_2} = \frac{R_1}{r}.$$

If the resistances of the batteries cannot be neglected, they must be added to R_1 and r, or

$$E_1(r + r'') = E_2(R_1 + r'). \tag{4}$$

By adding a resistance P to R_1 and Q to r, we have

$$E_1(r + r'' + Q) = E_2(R_1 + r' + P). \tag{5}$$

From (4) and (5) $E_1Q = E_2P,$

or $$\frac{E_1}{E_2} = \frac{P}{Q},$$

or the E. M. F's. of the two batteries are directly proportional to the added resistances after balancing in R_1 and r. The service testing set can be used for the resistance R_1 and r, the balance arms being used for this purpose.

Derivation of Formula for Finding Resistance of Battery.

(See Chapter III.)

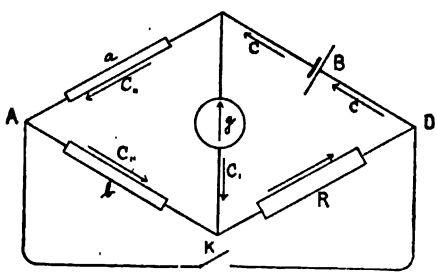


FIG. 24.—Connections for Finding Resistance of a Cell.

In Fig. 24 let E = E. M. F. of cell,
C = total battery current,
C_1 = current in g,
C_2 = current in a and b.

When key is open, current flows through the joint resistances $(a + b)$ and g, the resistance of which is $\frac{(a+b)g}{a+b+g}$.

$$C = \frac{E}{R + B + \frac{(a+b)g}{a+b+g}}$$

$$C_1 g = C_2(a + b) \qquad C_1 + C_2 = C$$

$$C_1 + \frac{C_1 g}{a+b} = C \quad \text{or} \quad C_1(a + b + g) = (a + b)C$$

or $$C_1 = \frac{E}{R + B + \frac{(a+b)g}{a+b+g}} \times \frac{a+b}{a+b+g}.$$

This reduces to

$$C_1 = \frac{E(a+b)}{(R+B)(a+b)+g(a+b+R+B)}. \qquad (1)$$

When the key is closed and A and D are at the same potential, current flows as though A and D were directly connected, current flowing in the divided circuit b and R in series with g, and the whole forming a divided circuit with a. This is shown in Fig. 25.

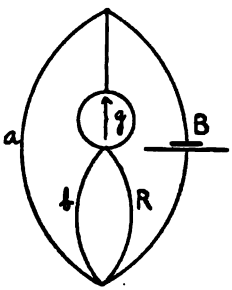


FIG. 25.

The resistance of b and R is $\frac{bR}{b+R}$.

The resistance of b, R, and g is $\frac{bR}{b+R}+g$.

The resistance of b, R, g, and a is $\frac{\left(\frac{bR}{b+R}+g\right)a}{\frac{bR}{b+R}+g+a}$.

$$C = \frac{E}{B+\frac{\left(\frac{bR}{b+R}+g\right)a}{\frac{bR}{b+R}+g+a}}$$

$$C_{11}a = C_1\left(\frac{bR}{b+R}+g\right) \qquad C_1+C_{11}=C$$

$$C_1+\frac{C_1\left(\frac{bR}{b+R}+g\right)}{a}=C$$

$$C_1\left(a+\frac{bR}{b+R}+g\right)=aC$$

$$C_1 = \frac{E}{B+\frac{\left(\frac{bR}{b+R}+g\right)a}{\frac{bR}{b+R}+g+a}} \times \frac{a}{a+\frac{bR}{b+R}+g} \qquad (2)$$

When the current in the galvanometer is the same, the deflection is the same and equation (1) = (2).

or

$$\frac{(b+R)a}{BbR+Bbg+Bba+BRg+BRa+abR+abg+aRg} = \frac{a+b}{aR+aB+bR+bB+ga+gb+gR+gB}.$$

This reduces to

$$aR(aR+bR+gb+gR) = bB(aR+bR+gb+gR),$$

or

$$aR = bB,$$

or

$$B = \frac{aR}{b}.$$

CHAPTER VII.

MAGNETISM AND ELECTROMAGNETISM.

Magnetism.

Magnetism is the science that teaches of the properties of magnets. The name *magnet* was originally applied to a mineral known as *magnetite,* an oxide of iron of the chemical composition Fe_3O_4, which in its native state has the power of attracting iron. It has the power of imparting its magnetic properties to pieces of iron or steel brought near it, and such pieces of iron or steel are then said to be *magnetized* and are then called *magnets.* Iron or steel may be magnetized in other ways, the principal of which is by means of the electric current.

The Compass.—One of the most common examples of a magnetic substance is seen in the ordinary mariner's compass needle, a pivotted needle, highly magnetized, which, when at rest and undisturbed by local magnets, takes a position that indicates magnetic north and south. The end of the needle that points towards magnetic north is called the *north-seeking pole,* or briefly the **north pole** of the needle, and similarly the other end is called the **south pole** of the needle.

This needle acts under the influence of some force, inherent in the earth and in the space surrounding it which causes it to take a certain definite position. The region surrounding the earth and near it seems to be under the influence of this force or of varying forces, the origin of which lies in different points on the earth's surface. These points are called the **magnetic poles** of the earth, one representing the concentration of all the forces exhibiting one peculiarity, which may be called **positive,** and which is known as the **north magnetic pole** of the earth; another, the concentration of all the forces of opposite peculiarity which may be distinguished by being called **negative** and which is known as the **south magnetic pole** of the earth.

Recent investigations seem to indicate that there is only one north magnetic pole but one or more south magnetic poles. Emanating and radiating from these poles, there may be considered an indefinite number of lines, the direction of which at any place representing the direction of the resulting forces due to the opposite poles at that place. These imaginary lines may be considered as form-

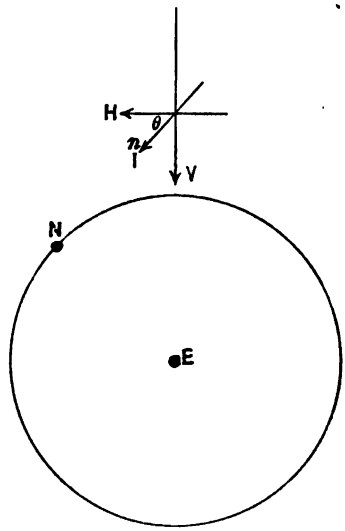


FIG. 26.—Illustrating Earth's Magnetic Force.

ing closed curves, running through the earth from the south to the north pole, and through the space surrounding the earth, from the north to the south pole.

At any place on the earth's surface, the direction of one of these imaginary lines would be that which a freely suspended magnetic needle would take.

In Fig. 26, let the circle *E* represent the cross-section of the earth and *N* the north magnetic pole. A freely suspended magnetic needle *n*, will turn so as to place itself in the direction of the magnetic lines at the place of suspension, and its north end will point towards the north magnetic pole, and it is urged towards the latter with a certain force called the **earth's total force**, designated by the letter *I*.

This force may be resolved into two forces, one parallel to the earth's surface, called H and the other vertical to the earth and called V.

If θ = the angle the needle makes with the horizontal

then $$H = I \cos \theta$$

$$V = I \sin \theta$$

and $$I = \sqrt{H^2 + V^2}.$$

As the point of suspension of the needle approaches the poles, the angle θ will increase, and when $\theta = 90°$

$$V = I \sin 90° = I.$$

At the pole then the horizontal force is zero, the vertical force is equal to the total force, and the needle points vertically up and down.

When θ becomes zero,

$$H = I \cos 0° = I,$$

and at that place, the needle is parallel to the earth's surface and there is no vertical force. The locus of all the places where the earth's vertical force is zero is called the **magnetic equator.**

The angle θ that the needle makes with the horizontal at any point on the earth's surface is called the **Dip.**

Magnetic Field.

All the space surrounding the earth and which is subject to the forces due to the poles is called the earth's magnetic field, and in general a magnetic field may be defined as **a space in which magnetic action takes place, or a region in which a magnet pole is acted on by a force tending to move it in one direction or another.** Magnetic fields may be produced by the earth, by magnets, by magnetic substances, by electromagnets, or by electric currents. The magnetic field of a magnetic substance is similar to that produced by the earth, and all magnets may be considered as small imitations of the earth, regarded as one huge magnet. For instance, an ordinary bar magnet has its poles and its magnetic equator or neutral line and its magnetic field surrounding it, represented by a number of lines forming curves through the magnet and the space surrounding it.

The poles of an ordinary bar magnet are close to the ends of the magnetic axis; they are of equal strength and opposite sign. In an indefinitely thin bar, uniformly magnetized, the poles are at the extremities of the magnet, and at these points the magnetic force is greatest.

In Fig. 27 is shown the magnetic field due to a bar magnet, in which the dotted lines represent the directions in which the forces due to the poles at *N* and *S* act, while the number of lines is a

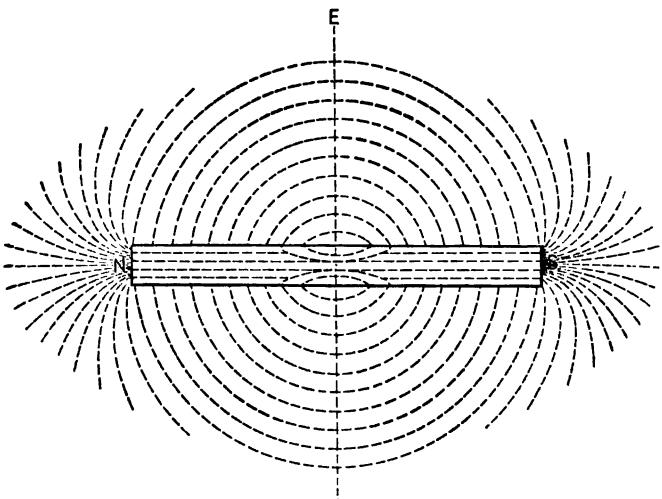


FIG. 27.—Magnetic Field Due to the Bar Magnet.

measure of the strength of the poles. All the lines pass through the central portion of the magnet, the *equator,* but begin to emerge from the sides of the magnet as the poles are approached on either side of the equator. Most of the lines pass through the interior of the magnet and emerge from the poles, and each line is continuous and completes its path in the region outside the magnet.

Free Magnetism.—Whenever the lines representing the magnetic field emanate from a magnetic substance and pass into the space surrounding it, the body is said to possess **free magnetism,** and any magnetic substance placed in this region will become magnetic and experience a force of attraction or repulsion.

Thus the magnetism of the bar magnet shown is all free and capable of producing magnetic induction.

Unit Magnetic Field.—A Unit Magnetic Field is defined to be one of such strength that it will act on a unit magnetic pole placed in the field with a force of one dyne.

A Unit Magnetic Pole is one of such strength that if placed in air one centimetre from a similar and equal pole, it will be repelled with a force of one dyne.

Thus, if it is said that the earth's horizontal component of its total force is .2 at any place, it is meant that at that place, a unit magnetic pole would be acted on with a force of .2 dyne.

The strength of a magnetic field may also be defined by the number of imaginary lines, portions of the closed curves, embraced in a given area at right angles to the direction of the lines. The intensity of the magnetic field at any point is represented by the number of these lines at that point, and a magnetic field has *unit intensity,* or a *unit magnetic field* exists when it *embraces one line, in air, per unit of area,* that is per square centimetre.

Laws of Magnetic Force.—

First Law.—Like magnetic poles repel one another; unlike magnetic poles attract one another.

Second Law.—The force exerted between two magnetic poles is proportional to the product of their strengths and is inversely proportional to the square of the distance between them.

Lines of Force Due to a Magnet Pole.—If the two magnetic poles are unit poles and are one centimetre apart, the force exerted between them is

$$f = \frac{mm'}{d^2} = \frac{1 \times 1}{1^2} = 1 \text{ dyne.}$$

From the definition of unit magnetic field, that a unit magnetic pole placed there is acted on by a force of one dyne, it follows that unit magnetic field must exist at unit distance from a unit pole. The surface of a sphere one centimetre in radius is equal to 4π square centimetres, and as unit field exists one centimetre from unit pole, or has one line of force per square centimetre, it follows that from every unit pole there must emanate 4π lines of force.

Magnetic Moment and Intensity of Magnetization.

If the strength of the poles of a magnet is m and the distance between them is l, the **moment of the magnet** is

$$M = m \times l.$$

The external effect of a magnet is the result of a certain condition of the metal which extends throughout the length of the bar, and any portion cut from the metal will exhibit the same magnetic qualities. If the magnetization of the whole magnet is uniform, the moment of every portion would be proportional to its volume.

The moment per unit of volume is called the **intensity of magnetization** and is denoted by I, or

$$I = \frac{ml}{V}$$

where V = volume.

If the cross-section is uniform, the strength of pole is $m = Is$, as $V = ls$, where s is the area of cross-section.

Lines of Force and Induction.

Lines of force are defined as imaginary lines, which by their direction show the resultant of the magnetic forces acting at the point, and by their number, the magnitude of the force. The direction of the lines of force is that in which a free isolated magnetic pole would tend to move if placed in the field, the positive direction being that in which a positive pole would be repelled by a north pole or attracted by a south magnetic pole. These are supposed to exist in air, and the number of lines that are embraced in a unit area at right angles to the direction of the lines is a measure of the intensity of the field at that point. If the earth's horizontal force was given as .2, it would mean .2 of unit strength, or that every square centimetre embraced .2 of a line of force, but as this is impossible, it would have such a strength that would be represented by 20 lines of force per square decimetre.

The strength or intensity of the field is usually denoted by H, and is independent of the source which produces the field. H is measured by the force which a unit pole would experience if placed in that field. Thus, if a pole of strength m is placed in a field of strength H, it would be acted on by a force of

$$F = mH \text{ dynes.}$$

Besides the lines of force which pass into the air, there are other lines which are conceived as only passing through the metal of the magnetic substance; these lines representing the *intensity* of magnetization in the magnet. The strength of pole m being equal to Is, and each unit pole having 4π lines, the total number of lines of magnetization in the magnet itself, independent of the lines of force in air, is $4\pi Is$, or per unit of area, $4\pi I$.

The resultant of the lines of force and the lines of magnetization are called **Lines of Induction.**

Magnetic Induction.

Magnetic induction is the phenomenon of inducing magnetism in a magnetic substance by the *influence* of another magnet, and a magnetic material placed in a magnetic field becomes magnetic by the influence of the lines of induction described above.

Soft iron lying in the magnetic field of the earth becomes magnetic, and of greater or less strength, depending on its position relative to the lines of induction of the earth's magnetism. Thus, a long, straight bar lying parallel to the lines of force or in the magnetic meridian may become strongly magnetic, the part pointing to the north of opposite polarity to that of the north magnetic pole of the earth. In this position it embraces a great many lines of force. As the bar is turned from the meridian, the number of lines embraced continually diminishes and the resulting induction grows less, until the bar is east and west, when its ends show practically no magnetism. However, in this position, the whole half of the bar lying broadside to north will have magnetism opposite to that of the north magnetic pole and opposite to the other half.

If the bar is held vertical, it will have induced in it, however it may be turned in azimuth, magnetism due to the vertical component of the earth's total force, the lower end having magnetism opposite to the magnetic pole of the hemisphere in which the experiment is made.

Magnetic induction takes place in any magnetic substance which is near enough to allow the lines of force from the magnetizing substance to pass through it. North and south polarity is always set up, and the induced polarity can always be told, if the direction

of the inducing field is known, for no matter what the shape of the magnetic substance, a south pole will always be formed where the lines of force *enter* the substance and a north pole where they *leave* it. In other words, poles of the inducing substance induce opposite polarity to themselves, and the pole nearer to the inducing magnet will be of the opposite kind.

A substance magnetized by induction exhibits all the properties of a magnet while under the influence of induction, but generally loses most of them when the magnetizing substance is removed. If the number of lines passing through the material placed in a magnetic field is greater than the number of lines that previously passed through the same space in air, the material is said to be **paramagnetic**, and if less than before, **diamagnetic.** Thus, the iron bar lying in the magnetic meridian was paramagnetic; if the rod had been zinc, the number of lines passing through the zinc would have been less than through the same space in air, and it would have been diamagnetic.

Paramagnetic and Diamagnetic Substances.

A list of some of the principal paramagnetic and diamagnetic substances is given:

Paramagnetic.			
Iron,	Nickel,	Cobalt,	Aluminum.
Diamagnetic.			
Bismuth,	Air,	Silver,	Water,
Antimony,	Mercury,	Copper,	Alcohol.
Zinc,	Lead,	Gold,	

When a material is lying in a magnetic field the total number of lines passing through the material per square centimetre of cross-section at right angles to the lines is a measure of the magnetic induction and is usually denoted by B. This B consists of the $4\pi I$ lines mentioned above as representing the intensity of magnetization per unit area of cross-section and the H lines due to the magnetizing force, or $B = 4\pi I + H$.

Magnetic Permeability and Susceptibility.

Suppose a magnetic field of strength H, and a magnetic material placed in it experiences an induction B; or, in other words, there are B lines per unit of area in the material, while in the same space in the air there were but H lines, then the ratio $\frac{B}{H}$ is called the *permeability* of that material, usually denoted by μ, which is called the **coefficient of permeability.** Similarly, if the intensity of magnetization becomes I, the ratio $\frac{I}{H}$ is called the *susceptibility* of that material, denoted by k, called the **coefficient of susceptibility.**

$$\mu = \frac{B}{H} \text{ and } k = \frac{I}{H} \text{ and } B = 4\pi I + H,$$

whence it follows that $\mu = 4\pi k + 1$.

Electromagnetism.

Electromagnetism treats of the relation existing between electric currents and magnetic fields.

Magnetic Field Due to Current in a Straight Conductor.

If a straight conductor is held over and parallel to a small pivotted magnetic needle which is pointing towards magnetic north, and an electric current is passed through the conductor, the needle will be deflected one way or another out of the magnetic meridian. This experiment shows that there must have been some force brought into existence by the current in the conductor that was not present when the current did not flow.

This deflection of the magnetic needle is not due directly to the electric current, as the conductor does not touch the needle in any way, but it is due to a condition established by the current, the setting up of a magnetic field around the conductor, and it is the reaction of the two magnetic fields, that due to the magnet and that due to the current, which causes the needle to take a position dependent on the resultant of the two forces.

A straight conductor carrying a current has then set up around it a magnetic field which is dependent for its intensity and on the

distance its properties are manifested directly on the strength of the current. This magnetic field consists of a series of concentric curves, or rings, surrounding the conductor, the lines representing the field being in every way similar to the lines of force of magnetic substances. These lines have no absolute geometrical form, but rather are a mass of whirls or eddies surrounding the conductor. They are brought into existence by the current, and increase with the current and die out with it, seeming to collapse like rubber bands that have been stretched, when the current has faded to zero, and spreading out as the current is increased. An idea is given of their form and direction in Fig. 28.

In Fig. 28, the lines of force are drawn as concentric circles around the conductor, but as a matter of fact as stated above they

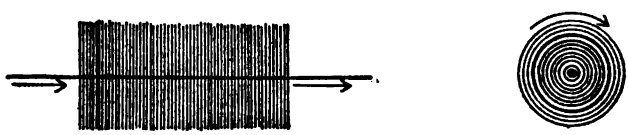


FIG. 28.—Magnetic Field due to Straight Current.

may or may not have a symmetrical form. In the right hand sketch, the central dot represents the conductor, with the current flowing away from the observer, in which case the positive direction of the lines of force is clockwise or right-handed and the heavy circle has been drawn to represent the resultant of all the lines of force due to the current. This field will remain of constant intensity as long as the current remains steady, but will change in strength as the current starts, stops, or changes its rate of flow.

Knowing now the character of the field set up around a conductor carrying a current and the field of the magnetic needle, it is easy to account for the deflection of the needle under the influence of a current of electricity.

The upper figure in Fig. 29 represents the cross-section of the conductor flowing away from the observer and marked *IN*, and the circle represents the resultant of the lines of force. Under the conductor and parallel to it is shown the cross-section of the needle,

the north end marked *N*. The positive direction of the magnetic whirls is clockwise, and these whirls apparently striking the north end of the needle, there is a reaction between the two magnetic fields, and both being positive, there is mutual repulsion, the field of the current being pushed out of its natural path, and the north end of the needle being repelled to the left. There is also attraction between the field of the current and the south pole of the needle, tending still more to deflect the north end of the needle to the left. If the needle were placed over the current, the north pole would be pushed to the right and opposite deflection would be the result.

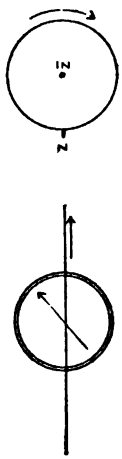


FIG. 29.

The resultant action of the two fields is also explained by the following general principle: **Whenever two different magnetic fields are near one another and capable of influencing one another, and one is fixed while the other is movable, the movable one will always tend to move to such a position that will cause the two fields to have one common path in one direction.**

In the above illustration, in order that the two fields may have one common path in one direction, the needle will have to turn at right angles to the conductor, when the magnetic lines due to the current would run through the needle from the south pole to the north, and from the north pole of the needle around the conductor in air to the south pole of the needle.

Rules for Remembering Direction of Field and Current.— The lower sketch shows the conductor over the needle and flowing up, the needle being deflected to the left. There are several rules for remembering the relation between the direction of the current and the direction of the deflection of the needle, one being the application of the word *snow,* illustrated in the above sketch. If the current is from south to north over the needle, the deflection of the north end of the needle is to the west, the initials of *south, north, over, west,* forming the word **snow.**

Conversely by knowing the direction of deflection, and the position of the needle in reference to the conductor, the direction of the current is at once known.

One of the simplest rules for remembering the direction of the lines of force due to a current is that known as the **Hand Rule.** *Grasp the conductor with the right hand with the thumb turned away from the hand and pointing in the direction in which the current is flowing. The direction in which the finger tips point is then the positive direction of the lines of force.*

Laws of Parallel Currents.

These laws may be stated here as they are so readily explained by a consideration of the magnetic fields surrounding conductors carrying currents, and illustrate so well the resultant action of those fields.

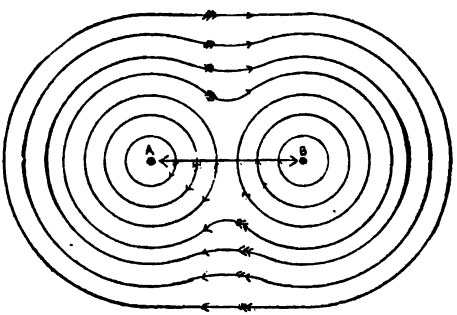


FIG. 30.—Magnetic Field of Parallel Conductors in Same Direction.

Parallel conductors carrying currents of electricity are mutually attracted if the current is flowing in each in the same direction, and are mutually repelled if the currents are flowing in opposite directions.

Fig. 30 shows two parallel conductors *A* and *B*, the current in each flowing away from the observer, and each surrounded by its own magnetic field, which is indicated by a few representative lines. The arrows show the positive direction of the lines of force, the same in both cases, each being right-handed or clockwise as viewed in the direction the current is flowing. The lines near the conductors are closed on themselves, but where they meet, they seem to absorb one another and each takes the path and continues the course of the other, which is the resultant path due to the

forces exerted by the separate fields. In the region between the conductors, it is seen that though the positive direction of the lines of force is in the same direction, at this point they are opposite, and each path by itself represents the direction a free north pole would move. Here then is like magnetism, and by the principle of resolution of forces, it is seen that the resultant will be something similar to the curves above.

In this illustration is seen the analogy of the lines of force to stretched rubber bands, there being a tension along the lines tending to draw the conductors together. The lines could be imagined to be replaced by one line joining *A* and *B* such that if all resistance to motion was overcome the conductors would be drawn together.

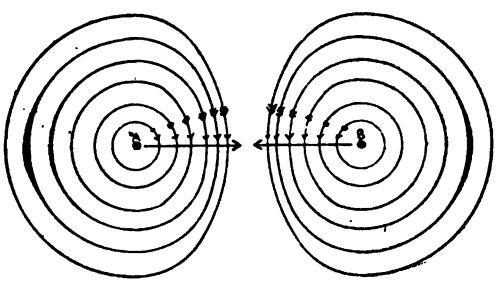


FIG. 31.—Magnetic Field of Parallel Conductors in Opposite Directions.

Fig. 31 shows two parallel conductors *A* and *B*, the current in *A* flowing away from the observer with its right-handed or clockwise field as viewed in the direction the current is flowing, and the current in *B* flowing towards the observer with its left-handed or anti-clockwise field as viewed in the direction opposite to that in which the current is flowing.

By the resolution of forces, it is seen that there is mutual repulsion between the fields in the region between the conductors, each field being compressed on its own conductor. The action of the two fields is such that there is compression across the lines of force while yet tension in the direction of their length.

As in the above case, the fields could be imagined to be replaced by a band in a state of compression which would cause the con-

ductors to be pushed apart if the resistance to compression was overcome.

The resolution of the forces acting in the two cases is shown by the following sketch:

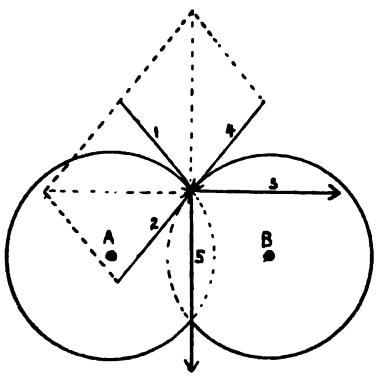


FIG. 32.—Resolution of Forces Due to Magnetic Field.

In Fig. 32 one line of force is taken to represent the field of *A*, and the north pole travelling in this line at a given instant is travelling in the direction represented by arrow 1, tangent to the circle of the line of force. At a similar instant, a free pole in the field of *B* is moving in the direction of arrow 2, both being clockwise. The resultant of these two forces is arrow 3, which is in a direction parallel to *AB*, or the line described by a pole tends to embrace both conductors, giving the resultant line as seen in the preceding figure of attraction.

If, on the other hand, the field of *B* is opposite to that of *A*, at the instant a free pole in the field of *A* is moving in the direction of arrow 1, one in the field of *B* is moving in the direction of arrow 4, the resultant of which is arrow 5, which is in a direction perpendicular to *AB*, or a force which tends to separate the fields, causing a compression and a corresponding repulsion of the conductors carrying the currents.

If the conductors are not parallel, the reaction of the two fields will tend to bring them parallel and in such a parallelism that will tend to make both the currents flow in the same direction.

In the left-hand diagram of Fig. 33, the fields due to the two currents would tend to cause the upper and lower halves of each conductor to approach one another so that the two conductors would be parallel and both currents flowing down. In the right-hand diagram, the right and left halves of each conductor would tend to approach each other, so as to make the conductors parallel, with the current flowing from right to left.

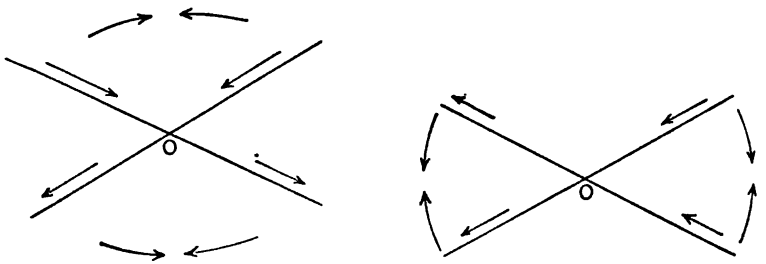


FIG. 33.—Oblique Currents.

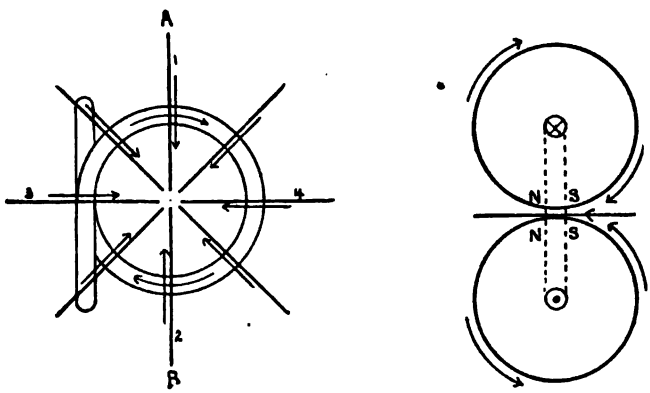
Magnetic Field Due to Current in a Coiled Conductor.

Having seen how the magnetic field is produced by a current flowing in a straight conductor, we are now in a position to take up the field produced by a current flowing in a conductor bent into a ring or spiral. In this case the magnetic field still surrounds the conductor as a series of whirls of lines of force, at any position the plane of the lines being normal to the conductor. Bending the conductor into a ring has the effect of increasing the intensity of the field in the center of the ring, or region near it, as it concentrates the lines of force at that point.

Figs. 34 and 35 represent a conductor carrying a current bent into a circle, one turn being made. Fig. 34 shows the current in the conductor flowing in a clockwise direction, and the lines radiating from the center show the projections of the magnetic lines surrounding the conductor, the positive direction, according to previous laws, being towards the center in the half of the circle that is nearer the eye. The magnetic lines are only those due to the ring of the conductor, not the straight portions of the conductor.

Fig. 35 shows a section of the conductor on the line *AB*, and revolved to the right 90°. The lines of force 1 and 2 are projected

as circles, 3 and 4 as a straight line and any intermediate lines as ovals. These latter are left out for the sake of clearness. The cross in the upper little circle ⊕ represents the tail of the arrow showing the direction of the current in the conductor, and the dot in the lower little circle ⊙ represents the head of the arrow. Remembering these directions, it is seen that the upper line of force has its positive direction in a clockwise direction and the lower in an anti-clockwise direction as shown by the arrows, and the inner portion of the center line is in the same direction.



FIGS. 34 and 35.—Magnetic Field Due to Coiled Conductor.

Remembering that the positive direction of these lines is the direction a free north pole would move, it is evident in the center it would move to the left, all the lines of force urging it in that direction. From the first law of magnetism, magnets of unlike polarity attract, and of the like polarity repel. As this free north pole would move to the left away from the left-hand side of the conductor, it is evident that that side must act as north polarity. Viewed from the right the current is flowing clockwise, which gives the rule: *If a spiral conductor carrying a current be viewed end on, and the current is flowing in a clockwise direction, then the nearer face is of south-seeking polarity and the further of north-seeking polarity.*

The right-hand face of the right-hand figure acts then as though it were a magnetic shell of south-seeking polarity and the opposite

face of north-seeking polarity. In the left-hand figure, the plane of the conductor nearer the eye is of south-seeking polarity and the farther side is of north-seeking polarity.

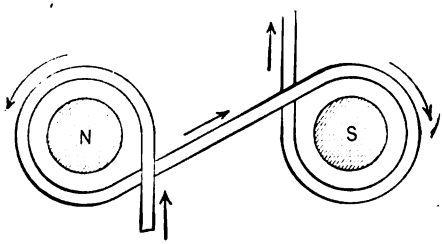


FIG. 36.—Two Core Polarity.

The rule given for determining the condition of polarity holds good for either a right-handed or left-handed spiral, as indicated in Fig. 36, showing opposite polarity produced in two cores by a single winding.

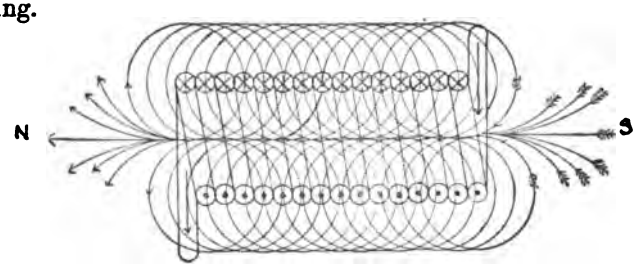


FIG. 37.—The Solenoid.

The Solenoid.

Fig. 37 represents the resultant magnetic field due to a conductor carrying a current, the conductor being bent into a number of turns, forming a spiral. The field is exactly similar to the case of one turn with the exception that the spiral forming the path is much longer, with the result that the field in the interior along the length of the spiral is almost uniform. Of course, if the conductor is bare, the turns must not touch in forming the spiral, but it is immaterial if the conductor is properly insulated.

Such a spiral is called a solenoid, and it acts exactly as an air magnet, reasoning as above showing the left-hand face to be of

north polarity and the right-hand face of south polarity. The intensity of the field in the interior is greatest at the center, gradually weakening towards the conductor. Only lines of force in the center are shown, but these are not the only lines, others being parallel to the center line in the interior and close to the inside of the conductor. At the ends, the lines of force spread out, the field weakening as the distance from the ends increases.

Magnetizing Force Due to a Solenoid.—It has been shown that a magnet of strength m placed in a magnetic field of intensity H is acted on by a force of

$$F = mH \text{ dynes.}$$

If the pole is of *unit* strength and moved through a distance l the work done, expressed in ergs, is

$$Fl = Hl. \qquad (1)$$

The work done in moving a conductor carrying a current through a magnetic field is equal to the *current times the number of lines cut,* or

$$\text{Work done} = \frac{CN}{10} \text{ ergs.} \qquad (2)$$

C is divided by 10 in order to reduce the number of amperes of current to the number of absolute units, as the work done is expressed in ergs.

From each unit pole there radiate 4π lines of force and each of these lines will cut each turn of the wire around the solenoid, as the unit pole is moved against the magnetic force. If there are S turns in the solenoid, the total number of lines cut is

$$N = 4\pi S,$$

and the total work done is

$$\text{Work done} = \frac{4\pi CS}{10} \text{ ergs.} \qquad (3)$$

If the length of the solenoid is l, that is, the length occupied by the winding, the work done against the magnetic force, is, according to equation (1) $= Hl$, and therefore (1) $=$ (3), or

$$H = \frac{4\pi CS}{10l}.$$

This is an expression for the intensity of field within a solenoid due to a current flowing in it, and is also the magnetizing force of the solenoid.

Open and Closed Magnetic Circuits.

A **closed magnetic circuit** is one in which the lines of force due to the magnet flow around a *complete* iron path; an **open magnetic circuit** is one in which the paths of the lines of force are broken by one or more air gaps. The *open* circuit exhibits *free* magnetism and produces and can induce definite polarity and is sometimes called a *polar* circuit, while the *closed* circuit possesses practically no free magnetism and produces induction in neighboring magnetic substances only by the *leakage* of magnetic lines from it.

The ordinary bar magnet and the solenoid are examples of open magnetic circuits, and forms of open circuits are extensively used with continuous currents while closed circuits find their greatest uses in alternating currents.

The Electromagnet.

When no current is flowing through the conductor forming the solenoid, there is no magnetizing force to produce a magnetic field, either in the space surrounding the solenoid or in the column of air enclosed by the solenoid. When current flows, producing a magnetizing force, the column of air inside is subjected to a magnetizing force, producing a field of intensity H, and also an induction B. The coefficient of permeability $\mu = \frac{B}{H}$, of air $= 1$, as the induction B by definition is equal to H for the substance, air.

If, however, the conductor forming the solenoid is not wound around a column of air, but around a substance of high permeability, as soft iron, the number of lines of induction B that now thread through the iron is very much increased, and the intensity of magnetization of the iron is μ times the intensity of the air field H. Suppose there were 50 lines of force per unit of area in the air column, and the coefficient of permeability was 300, then there would be 15,000 lines per unit of area in the iron core.

Such an arrangement of solenoid and soft iron core is termed an **electromagnet**, the iron core exhibiting the properties of a magnet to its fullest extent only when current is flowing.

An electromagnet is a contrivance intended to exert a force of attraction on a movable piece of iron called the *armature*. Polarity

is induced in this armature by the magnetic field of the electromagnet, after which attraction takes place, the armature being made movable so it can approach the core of the electromagnet. Before induction can take place, there must be free magnetism, so the primary condition is that the magnetic circuit must be an *open* one.

The design of electromagnets depends on the character of work they are expected to do, whether they are to be *slow* or *quick-acting*, and whether the range of motion of the armature is to be *short* or *long*.

Examples of Electromagnets.—A very common and typical form of electromagnet is shown in Fig. 38.

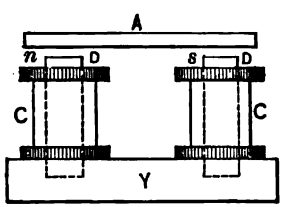


FIG. 38.—Typical Double-Coil Electromagnet.

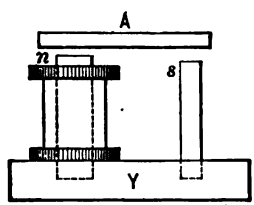


FIG. 39.—Club-Foot Electromagnet.

This consists of two coils of fine wire, *C*, wound oppositely on two bobbins which are slipped over the iron cores, *D*, which are secured to the base of magnetic material, *Y*, called the *yoke*. When current is sent through the coils, poles of opposite polarity are produced in the ends of the cores, *D*, the open magnetic circuit being through the two cores and the yoke. Above the upper ends of the cores is secured the *armature*, *A*, of soft iron, and so pivoted that it can approach the cores. It is made large enough to project slightly over the whole area of the cores which are usually circular. The free poles in the ends of the cores induce opposite polarity in the ends of the armature, after which attraction takes place and the armature moves towards the cores and brings up against them, forming a closed magnetic circuit. The armature will remain attracted as long as current flows, but when it is broken, the magnetic field is dissipated and the armature is usually provided

with some arrangement by which it is returned to its original position.

This form of electromagnet is very common and is used largely in vibrating bells, relays, and like appliances.

Fig. 39 shows a one-coil electromagnet, known as a **club-foot** electromagnet.

This differs from the two-coil electromagnet in that it only has one coil, the magnetic circuit being completed through the other core which is unwound, and which has the same polarity as the lower end of the wound core and the yoke. Its action is the same as the two-coil type.

This saves the winding of one magnet but diminishes the pull on the armature.

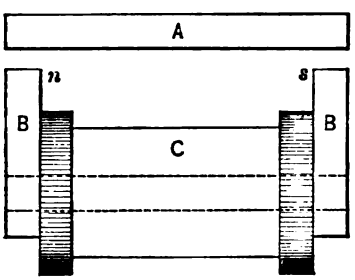


FIG. 40.—One-Coil Electromagnet.

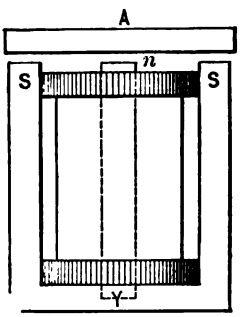


FIG. 41.—Iron-Clad Electromagnet.

Fig. 40 shows another and very common form of a **one-coil** electromagnet.

In this form the core forms the yoke and is fitted with two end plates, *B* and *B*, secured to it, in which opposite poles are produced. These poles in turn induce opposite polarity in *A* and the armature is attracted. This is a very compact form and is used largely in resistances for starting motors and other appliances.

Fig. 41 shows another form of one-coil electromagnet, known as the **iron-clad** type.

In this form the iron core is secured to and inside the bottom of a pot, and on the core is slipped the bobbin containing the winding. The upper end of the core forms one pole while the whole

upper rim of the pot forms the other, and the armature consists of a disc or lid of the same diameter as the pot.

All the foregoing types of electromagnets are examples of forms capable of exercising a strong pull over a short range.

For a weak pull over a long range, the ordinary solenoid with a movable core is used, as shown in Fig. 42.

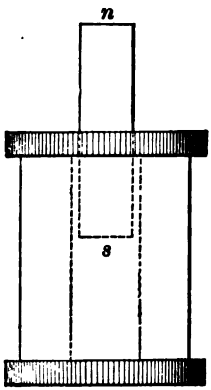


FIG. 42.—Long-Range Electromagnet.

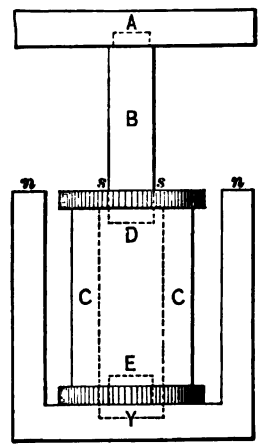


FIG. 43.—Stopped Solenoid.

When current is sent through the coils of this electromagnet, the core is sucked into the coil and the pull is greatest when the entering end reaches the further end of the coil. The pull in this form is not nearly as great as the form of Fig. 37, but the range of motion is very much increased.

Double Magnetic Circuit.—A modification of the above is shown in Fig. 43.

In this the magnetizing coil is slipped over a short core, *E*, which is secured to the yoke, *Y*, which is also provided with two limbs, *n* and *n*. The armature, *A*, is of the ordinary shape and is secured to a core, *B*, which is sucked into the coil when current is turned on. The dimensions are such that the bottom of *D* comes up against the top of *E* just when the armature brings up against the limbs *n* and *n*. This arrangement produces a double pull as the

magnetic field is divided, as the magnetic lines through B and E divide at the yoke and pass through the limbs n and n then through the ends of A to B again.

These last two forms are used in the mechanism of electric arc lamps and in some forms of automatic starting resistances for electric motors.

Magnetic Circuit.

By a magnetic circuit is meant the path of the magnetic lines of force, and it has been shown that these lines tend to make closed curves, either passing entirely through magnetic substances or partly through them and partly through air. Whatever the form of the magnetic circuit, its function is to direct the lines of force and the material of the circuit governs the resistance offered to the flow of the magnetic lines. Although these lines have no material existence, yet they can best be explained by their analogy to the electric current and considered as actually *flowing* in the magnetic circuit. In the magnetic circuit there is a leakage of the lines of force just as in the electric circuit there is a leakage of current.

The *total number of lines* in a magnetic circuit is generally referred to as the **magnetic flux.**

Magnetic Potential.—It has been shown that an electric current cannot exist in a conductor unless there is a *difference of electric potential* between the ends of the conductor, and there can be no magnetic lines of force produced unless there is a *difference of magnetic potential.*

Magnetic potential is measured by the work done in moving a unit magnet pole against the magnetic forces, and it has been shown that the magnetizing force due to a solenoid is

$$\text{work done} = \frac{4\pi CS}{10} \text{ ergs,}$$

where $C =$ current in amperes,

$S =$ number of turns of conductor on the solenoid.

As the magnetic potential is equal to the work done against the magnetic forces, it follows that it is equal to the magnetizing force of the current, or

$$\text{the magnetic potential} = \frac{4\pi CS}{10}.$$

To complete the analogy to the electric current, the magnetic potential is given the name **magnetomotive force,** and is defined as that force which tends to force magnetic lines through a magnetic circuit. It is designated as M. M. F.

The expression for M. M. F. contains only the variable factors, C and S, and is therefore directly proportional to their product CS, an expression which is called **ampere turns.** Experiment shows that as long as the number of ampere turns is constant, the M. M. F. will be constant; that is, one turn of conductor carrying 100 amperes will produce the same magnetization or M. M. F. as 100 turns carrying one ampere. It is also immaterial how far apart or how close together the turns are wound, the resulting M. M. F. will be the same.

Law of Magnetic Circuit.—Just as in the electric circuit, we have the law that

$$\text{total current} = \frac{\text{total E. M. F.}}{\text{total resistance}},$$

in the magnetic circuit we have

$$\text{total number of lines} = \frac{\text{total M. M. F.}}{\text{total magnetic resistance}}.$$

The total number of lines of force that a given magnetomotive force can force through a magnetic circuit depends on the magnetic resistance of the circuit, and this magnetic resistance is called its **reluctance.**

The magnetic law can now be stated in words, **that the magnetic flux in any magnetic circuit is directly proportional to the magnetomotive force and inversely proportional to the reluctance,** or in symbols,

$$N = \frac{\text{M. M. F.}}{Z}.$$

Reluctance.—This property of a magnetic material depends not only on the substance itself, but on its dimensions, varying directly as its *length* and inversely as its *area of cross-section.* It also varies inversely as its *permeability,* the higher the permeability, the less its resistance to the magnetic lines. For any portion of a magnetic

circuit, the reluctance of any portion is given by the expression

$$Z = \frac{l}{\mu a},$$

where Z = reluctance,

l = length of the path in centimetres,

and a = cross-sectional area in square centimetres.

If, as generally the case, there are air gaps in a magnetic circuit, the reluctance of the whole is much increased, due to the low permeability of air; the reluctance also depending on the dimensions of the air gap.

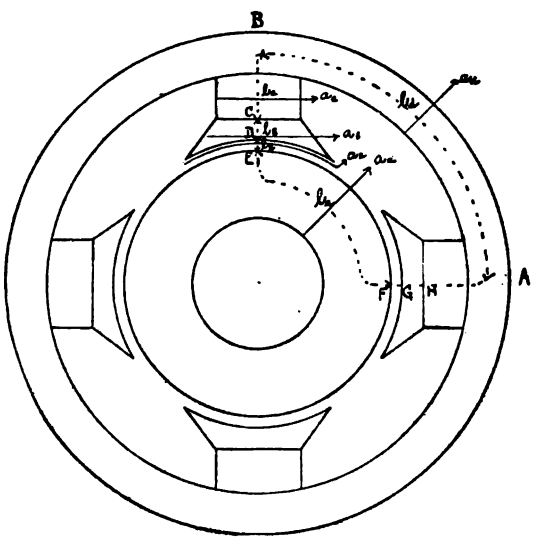


FIG. 44.—Typical Magnetic Circuit.

Joints also increase the reluctance, the amount of increase being a matter of experiment for each particular kind of joint.

Great heat increases the reluctance, but the temperature at which this is manifested is very seldom met in ordinary magnetic circuits.

Typical Magnetic Circuit.—In many combinations of electromagnets there are one or more magnetic circuits, but the data for each one may be determined separately, and the total joint effect

calculated. Examples of magnetic circuits will be shown later under the head of fields of dynamos and motors, but a typical circuit is inserted here.

Fig. 44 shows a typical four-pole magnet frame, in which there are four closed magnetic circuits. One of these fields is represented by the dotted line, through the magnet frame, the core pieces, the pole pieces, the air gaps, and the armature.

If a = area of cross-section of the different parts shown,

l = length of corresponding parts,

μ = coefficient of permeability of corresponding parts,

then the reluctance

from A to B $= \frac{l_d}{\mu_d a_d}$,

B to C and A to $H = \frac{l_c}{\mu_c a_c}$,

C to D and H to $G = \frac{l_b}{\mu_b a_b}$,

D to E and G to $F = \frac{l_e}{\mu_e a_e}$, $\mu = 1$ for air.

E to F $= \frac{l_a}{\mu_a a_a}$.

If all the magnetic parts of the circuit are of the same material $\mu_a = \mu_b = \mu_c = \mu_d$.

If the magnetic field is due to a current of C amperes with S turns, then the full expression between the magnetomotive force, the reluctance, and the total number of lines N is, assuming the same material,

$$N = \frac{4\pi CS}{10\left(\frac{l_a}{\mu a_a} + \frac{2l_e}{a_e} + \frac{2l_b}{\mu a_b} + \frac{2l_c}{\mu a} + \frac{l_d}{\mu a_d}\right)}.$$

To this denominator should be added the reluctance of the joints, which being known by experiment N can be calculated for a given number of ampere turns, or N being known from the E. M. F. to be generated, CS the necessary number of ampere turns can be calculated.

Residual Magnetism.

Suppose a piece of soft iron which exhibits no, or practically no, magnetism is made the core of a solenoid. When current is sent through the solenoid, the core at once evinces strong magnetic properties, due to its permeability. If now the solenoid current is turned off, it is found that the soft iron will now show magnetic properties, although in all other respects it is the same as before. The magnetization that is left in the iron is called **residual magnetism**, and the property of acquiring residual magnetism is called **retentivity**. The amount of magnetism retained after the magnetizing force is removed is called **remanence**. If the magnetizing current is reversed, the remanence disappears and if the current is the same as before, the core will be as highly magnetized with the opposite polarity. The force necessary to reduce the remanence to zero is called the **coercive force**, being a fraction of the total magnetizing force.

Certain substances show more residual magnetism than others, soft annealed iron showing much more than hard iron or steel, though the latter substances will hold their magnetism longer than the former, requiring a greater coercive force. Residual magnetism is greater when the current is gradually diminished, for when it is suddenly turned off there is a momentarily induced current of opposite direction which tends to destroy the residual magnetism. Mechanical shocks or changes of temper affect residual magnetism, especially in the softer varieties of iron, a gentle tap at times being sufficient to destroy it. Residual magnetism also gradually disappears in time, though varieties of hard iron or steel will nearly always show traces of it.

Measurement of Magnetic Fields.

In measuring the strength of a magnetic field what is desired is the total intensity of the field, and is calculated from the formula previously given

$$B = 4\pi I + H,$$

or

$$I = \frac{B - H}{4\pi}.$$

It is not necessary to make an exact measurement of the magnetic fields of dynamos on board ship, so the method of investigation will only be hinted at, exact methods requiring the use of instruments only found in laboratories. A small induction coil is connected to a ballistic galvanometer with its plane at right angles to the direction of the field. This is suddenly withdrawn to a place where the field is sensibly zero, when a deflection of the galvanometer needle is produced, owing to the current induced in the coil. This deflection is compared with the throw obtained by turning over quickly a large induction coil lying horizontally in the earth's field, this throw being proportional to the earth's vertical force.

It is frequently of importance to know how far the action of a magnetic field of a dynamo is felt from the machine, or to investigate the stray field of a generator; that is the lines of force that do not pass through the armature, and are not available for the induction of currents. This may readily be done by the vibration of an ordinary horizontal compass needle.

A compass needle when at rest, and only under the action of the earth's force, will point to magnetic north and if drawn aside from that position will vibrate from one side of north to the other, the arc of the angle described gradually lessening until the needle is again at rest and points north. During this time, the needle will make a number of vibrations depending upon the strength of the earth's horizontal force at that place. If now this same needle is made to vibrate in some other magnetic field, as the stray field of a dynamo, it will vibrate under the combined action of two forces, that of the stray field in addition to the earth's field. The square of the number of vibrations is proportional to the force under which the needle vibrates, and if the number of vibrations is counted for the same interval of time in the two cases, the forces are proportional to the squares of the number of vibrations in that time.

If n is the number of vibrations due to H, the earth's horizontal force, and n' the number due to the combined forces H' then $H' = \frac{Hn'^2}{n^2}$. The nearer n' approaches n the nearer H' approaches H. The needle may be vibrated at different distances from the dynamo or motor, and the combined forces of the earth

and machine may be calculated in terms of H, and the point noted where n' becomes equal to n, when $H' = H$, or the influence of the field has disappeared. This will give the distance in one direction where the stray field is zero, and the operation can be repeated in different directions. In making these experiments, the field of the machine should be excited to its fullest magnetization so the extreme distance will be known at which any external field exerts influence.

CHAPTER VIII.

ELECTROMAGNETIC INDUCTION.

Induction as used in electromagnetism may be defined as the mutual reaction that takes place between a magnetic field and a current of electricity flowing in a closed conductor lying in the influence of that field. It is immaterial in what manner the field is produced, and it may even be produced by the current of electricity itself, in which case the mutual action takes place between the current and the field that is produced by it.

It has been shown that currents of electricity flowing in closed conductors set up around the conductors magnetic fields, which are uniform in strength as long as the current is steady. Unless influenced by some external magnetic disturbance, the magnetic lines will be constant in number, direction, and position just as long as there is no change in the strength of the current. The intensity of this field will change as the current starts, stops or in any way alters its rate of flow.

If now there is a closed conductor without current, and by any means external to the conductor, a magnetic field is set up around it, it will be found that there is indication of current in the conductor as long as there is any change in the intensity of the field around the conductor. When once the field around the conductor is constant, then indication of current in the conductor ceases, although the field still surrounds it.

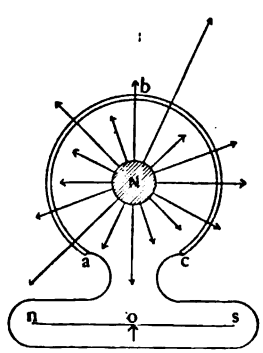


FIG. 45.—Electromagnetic Induction.

Suppose we have a closed conductor *a*, *b*, *c*, of the shape shown in Fig. 45, the circuit being completed around a small compass needle *n*, *s*, pivoted at *O*, the whole so arranged that the conductor

and connecting wires are parallel to the needle. If a pole of a permanent magnet N is thrust into the ring formed by the conductor, the magnetic lines due to this magnet spread out as shown in the figure, some passing through the conductor and others passing through the space enclosed by it. This magnetic field reacts on the conductor, setting up around it a magnetic field which in turn produces a current in the conductor. This process is called **induction,** and the current induced is manifested by the needle, *n, s* being deflected, due to the induced current flowing around it. This induced current is only noticed during the time that there is relative motion between the field of the magnet and the conductor, for as soon as the magnet is held steady in any one position, although the intensity of the field remains the same, there is no manifestation of current. The energy of pushing the magnet towards the conductor has been converted into electric current and when the magnet is at rest, there is no energy expended and no currents induced.

If the magnet was held steady and the conductor pulled away from it, there would be the same phenomenon exhibited, except that the needle would be deflected in the other direction. Approaching the south pole would produce a current in the opposite direction from that induced by the approach of the north pole.

The nearer that the pole is approached to the plane of the conductor, the greater is the deflection of the needle, showing greater current induced as more lines of force from the magnet pass through the coil.

Fig. 46 shows how more lines would pass as the magnet is approached nearer and nearer.

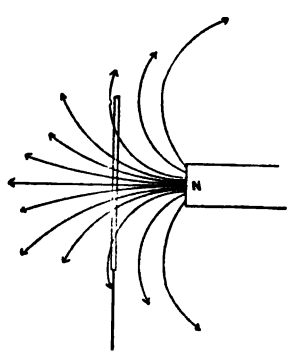


FIG. 46.

This experiment illustrates the first principle of induction, showing that **currents are induced in closed coils through which lines of force of an external magnetic field pass, as long as there is such relative motion between them as to alter the number of lines that pass through the coils.**

The direction of an induced current in a closed coil depends upon the direction of the lines relative to the movement of the conductor, upon the number of lines and whether the motion tends to increase or decrease the number of lines that pass through the coil. As it is important to know the direction of induced currents under certain circumstances, the rules for determining this direction or the laws of induction, as they are called, are given.

Determination of Direction of an Induced Current.—One of the simplest and most easily remembered rules is that given by Fleming, as follows: *Arrange the thumb and first two fingers of the right hand to point in three directions at right angles to each other. If the first finger points in the positive direction of the lines of force, and the thumb in the direction of the motion of the conductor, then then middle finger will point in the direction of the induced current.*

Laws of Induction.—1. A decrease in the number of lines of force that are cut by a closed coil produces a direct current, that is, a current of such direction, that if one looks along the positive direction of the lines of force, it will flow in the closed coil in the direction the hands of a clock move, or clockwise.

2. An increase in the number of lines of force that are cut by a closed coil produces an inverse current, that is, a current of such direction that if one looks along the positive direction of the lines of force, it will flow in the closed coil in a direction opposite to that of the hands of a clock, or anti-clockwise.

3. The E. M. F. generated is proportional to the rate of decrease of the number of lines of force cut.

If the *N* pole of the magnet referred to above is thrust into the ring at right angles to the plane of the paper from the near side of the paper, there is an increase in the number of the lines that pass through the coil and the observer on this side of the paper is looking along the positive direction of the lines of force, so the resulting current is inverse or anti-clockwise as viewed by the observer. The effect of this induced current is to make the near side of the coil a magnetic shell of north polarity. We then have the effect of a north pole approaching a north pole, which produces repulsion between them and which is manifested by its requiring greater force to thrust in the magnet as it approaches the coil.

In pulling away the magnet (N pole) from the coil or the coil from the magnet (N pole), there is a decrease in the number of lines of force that pass through the coil, and still looking along the positive direction of the lines of force from this side, the resulting current is direct, or clockwise, tending to make this side of the coil a shell of south polarity. We have now the effect of a north pole being pulled away from a south pole or vice versa, causing an attractive force between them, which is manifested in the greater force required to separate them.

Lenz's Law.—This phenomenon of induced currents is summed up in Lenz's law, which states that "**in all cases of electromagnetic induction, the induced currents have such a direction that by their reaction, they tend to stop the motion which produces them.**"

Illustration of Induction.

As a further illustration of the laws of induction suppose we had a circular closed coil lying in a magnetic field, the plane of the coil being at right angles to the lines of force and so arranged that the coil could be revolved about the extremities of one of its diameters.

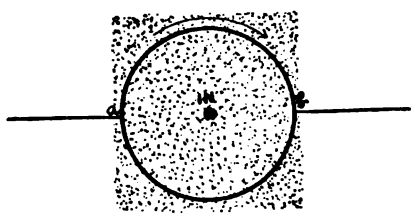


FIG. 47.—Illustration of Induction.

In Fig. 47 the lines of force are represented by the dots running through the paper, the observer on this side looking along the positive direction of the lines. As long as there is no movement of the coil, there is no induced current. Imagine the coil to be revolved on the axis a, b, the upper half turning into the paper, then there is a decrease in the number of lines that pass through the coil, and from the first law of induction, the induced current should be in the direction shown by the arrow. Now the converse of this

is also true, and if a current flows in the direction of the arrow, then the resultant field, within the coil, has the direction shown by the positive direction of the lines. A free north pole would be repelled from this side of the paper, showing that this side is of south polarity, a fact previously shown as due to a clockwise current. The field due to a current flowing in the conductor in the direction of the arrow is not the same as the imaginary field above consisting of parallel straight lines, but the resultant field, within the coil, may be imagined to be represented by one line, shown by the heavy dot and marked *IN*, that being its positive direction.

From the above it is seen that there is the same relative connection between the directions of the lines of force and the resulting induced current as there is between a steady current and its resultant field.

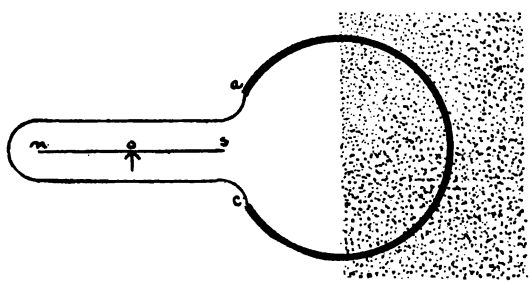


FIG. 48.—Illustration of Induction.

If, instead of approaching a magnet with its lines of force issuing in all directions to our closed coil, suppose we imagine this coil to be thrust into a uniform magnetic field as represented in Fig. 48.

The magnetic field is represented as before by the dots, and the observer is looking along the positive direction of the lines of force. As the closed coil *a, c* is moved from left to right into and at right angles to the magnetic field, there is an induced current in *a, c* due to the change in the number of lines that pass through the coil. It has already been noted that for the induction of current, there must be a *change* in the number of lines passing through the coil. If the coil is moved up and down the plane of the paper while lying in the field, there will be as many lines entering the coil on

one side as are leaving it on the other, so there will be no change and no induced current. Similarly, if the coil while parallel to the plane of the paper is moved up and down through the paper, there will be no induction. The above phenomenon is noticed when there is no change of intensity of the field, for if the number of lines at any portion is greater than at another, there will be a change in the number of lines passing through the coil, and so there will be induction of current.

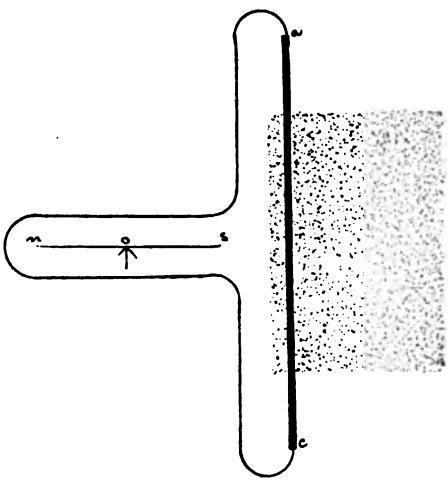


FIG. 49.—Illustration of Induction.

If the coil while lying at right angles to the lines was revolved about one of its diameters, there would be induction, for the number of lines that passed through the coil would then vary from a maximum to a minimum.

Suppose now the conductor *a, c* instead of forming a closed coil is straightened out and forms a long straight conductor, so in the sense we have been speaking, there is no closed coil. This is represented in Fig. 49.

If this straight conductor *a, c* is moved from left to right at right angles to the magnetic field and into it, it will be found that there is an induced current precisely as in the case where the conductor was bent into a circular coil. Here the induced current

cannot be said to be due to the change in the number of lines that pass through the coil, for there is no coil, but the current is induced by the conductor *cutting* the lines of force. If the conductor is moved parallel to the lines there is no cutting and no current.

This illustrates the principle of induction that **a conductor moved across a magnetic field so as to cut the lines of force, there is an E. M. F. generated which tends to produce an induced current in that conductor.** If the cutting be made continuous a continuous induced current will be the result.

The distinction between the currents induced in a conductor by a change in the number of lines that pass through the coil and by a conductor cutting across lines of force is not so sharp as it might appear. The induced current in either case is due to the same movement, and every conductor carrying a current forms part of a closed circuit, and while a conductor may be cutting lines of force, yet those lines must be passing through a closed coil of which the conductor is part, and the lines are passing into and out of the coil at the exact rate that the conductor is cutting them. The distinction is made between the two, as some examples of induction are better explained by one method and others by the other, and the application of both should be understood.

In either case, it is not a current that is generated, but rather an E. M. F. and we speak of the generation of E. M. F. and the induction of current, the latter following as a result of the former.

Different Methods of Induction.

As a result of induction, an E. M. F. may be generated in a closed conductor, or currents may be induced in it, by three different methods; that is, by electromagnetic induction, by self-induction and by mutual induction.

In **electromagnetic induction,** as already explained, the change in the number of lines of force which pass through the closed conductor is due to some relative movement between the conductor and the magnetic field. This is the underlying principle of all dynamo electric machines.

In **self-induction,** the change in the number of lines of force is caused by changes in the current that is producing the field, and

any change produces a corresponding E. M. F. which opposes that change and which tends to keep the current at a constant strength. In dynamos and motors self-induction takes place in the coils of the armature that are passing under the brushes, in the positions in which the current is reversed, or is dying out, or starting in the other direction.

In **mutual induction,** there are two or more closed conductors, in which any change in the field of one due to any change in its current acts on the other to increase or decrease its field, and consequently its current. The action is mutual: one acts or reacts on the other. This is the principle of the transformer or induction coil, or of a dynamo in which there is no moving part, the number of lines cut by one conductor being caused by changes of current in the other.

Self-Induction.

This is a case of induction in which an electric reaction takes place between a magnetic field and the electric current which produces the field. This action prevents the instantaneous rise and fall of a current in a closed conductor. While the phenomenon of self-induction is almost imperceptible in the case of a simple conductor carrying a current, yet the principle may be pointed out by means of a straight single current and the magnetic field brought into existence by it. It has been shown that the magnetic field due to a current flowing in a straight conductor surrounds the conductor as a series of concentric rings or whirls, the number of lines of force remaining constant as soon as the current reaches a steady value; the number increasing or decreasing with the current. When there is no current there is no magnetic field, but as soon as the faintest current flows, the lines of force are brought into existence. These lines of force may be considered as waves expanding from the very center of the conductor as a source of disturbance, and in their expansion they thread through or cut the conductor, and here is produced a simple case of electromagnetic induction, there being relative motion between the conductor and the field produced by the current. This current induced by the field, which in turn is produced by the original current, is in the opposite direction to that

of the original current and tends to weaken it, or to delay the current in reaching its maximum value.

As long as the original current is increasing, the lines of force are expanding as a series of waves and the current is being constantly retarded by the induced current, but as soon as the current becomes steady, there ceases to be relative motion between the field and the conductors and the induction ceases.

If the current becomes weakened the lines of force tend to collapse on the conductor, and this cutting of the conductor by these lines induces a current in the same direction as that of the original current, and which tends to keep the current from weakening. If the current is suddenly stopped, there is a quicker motion to the lines of force and this induced current may have an instantaneous appreciable value.

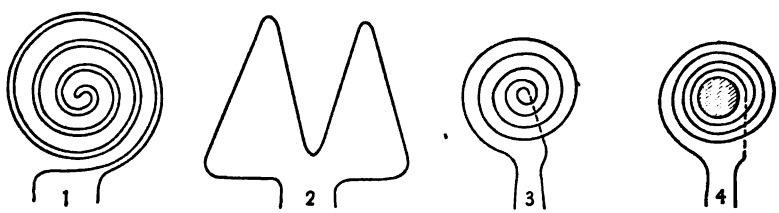


FIG. 50.—Forms of Self-Induction Circuits.

The E. M. F. of the momentary induced current may have a value considerably higher than that of the original current, and it is this high E. M. F. which produces the spark noticed whenever a circuit is broken, for the induced current tends to flow, though the original current be broken, and the high E. M. F. generated tends to bridge over the circuit where broken, volatilizing portions of the metal circuit and maintaining an arc for a brief interval across the space where the circuit is interrupted.

Forms of Inductive Circuits.—The amount of self-induction of an electrical circuit depends on its geometrical form. Fig. 50 shows some forms of typical circuits.

Type 1 shows that a current entering one of the terminals flows as many times around the helix in one direction as it does in the opposite direction, and in consequence the magnetic field set up by

one series of convolutions is counteracted by that of the other series and there is practically no self-induction. This is known as a non-inductive resistance and the *double winding* is used for the coils of standard resistances.

Type 2 shows very little self-induction but type 3 shows more. If the conductor of type 3 be made of many turns of wire close together, the effect of self-induction may be very marked. It will be still more marked if these turns are wound on an iron core, as type 4, as in the case of an ordinary electromagnet, for then there are many more lines of force due to the permeability of the metal. The lines of force in expanding from and collapsing on the conductor as the original current is increased or decreased, not only cut the portion of the conductor from which they emanate, but also the turns lying on either side for a considerable distance, so the total effect is that of all the lines of force due to each turn cutting a great many of the other turns.

Coefficient of Self-Induction.—The number of lines of force produced by a current is directly proportional to the current in a region where the permeability of the surrounding medium is constant, and any change in the current produces a proportional change in the number of lines of force.

A circuit has unit inductance when a rate of change of current of one C. G. S. unit per second produces one C. G. S. unit of E. M. F. One C. G. S. unit of E. M. F. is produced by the cutting of one line of force per second. Hence, the elements of current and number of lines are connected by the inductance, L, and since the number of lines is proportional to the current, we have the following relation:

$$L = \frac{N}{C}.$$

This coefficient, L, is constant for all values of C and depends on the form of the circuit. In a magnetic substance, the permeability varies with the current, and therefore L will vary with the degree of magnetization.

If a coil has S turns, the total cutting of magnetic lines is SN, and

$$LC = SN.$$

Since in circuits without magnetic cores, N is proportional to S, L must be proportional to S^2. The retardation of the current whether increasing or decreasing varies directly as the square of the number of turns of the conductor. The retardation in a coil of 100 turns would be 100 times as great as in a coil of 10 turns.

Since

$$N = \frac{4\pi CS}{10Z} \text{ (see Magnetic Circuit)}$$

$$L = \frac{4\pi S^2}{10Z} \text{ C. G. S. units,}$$

or

$$L = \frac{4\pi S^2}{10^{10}Z} \text{ henries.}$$

Mutual Induction.

The phenomena of self-induction and mutual induction are explained by the same electrical principles; self-induction being manifested in a closed conductor, the induction taking place in itself, while in mutual induction, the induction takes place in some adjoining separate closed circuit. However, the phenomenon of mutual induction may be accompanied by self-induction.

Suppose there are two parallel conductors, A and B, Fig. 51, each forming a portion of a closed circuit. If in A current is established from some outside source, the usual magnetic field will be set up around it. As current flows, the lines of force will expand as waves from the conductor as a source of disturbance, and if the current is flowing in the direction marked IN, the positive direction of the lines of force would be clockwise as shown by arrow 1. These waves expand, provided the current in A increases, until the conductor B is reached which up to this time has no current flowing in it. Immediately B acts as a new center of disturbance and a series of waves expand from it, the positive direction,

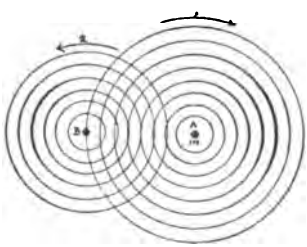


FIG. 51.—Illustrating Reversal of Current Due to Induction.

however, being now opposed to that due to A. Setting up these lines around B has the effect of inducing a current in B which is in existence until the current in A becomes steady. A change of current then in A has resulted in a momentarily induced current in B, but of the opposite direction.

It is impossible to depict by diagram just how or why this reversal of the positive direction of the lines of force takes place, when the current in one is increasing, but if the analogy of the lines of force to water waves be accepted, it is readily shown.

But first suppose, however, that the current in A is steady and that the field due to this current embraces or surrounds B. If the current in A is now weakened, the lines of force surrounding A will collapse on A and in doing so will cut through B, which will become a center of disturbance of another series of lines, which will expand as long as those of A collapse, but which will disappear as soon as the current in A becomes steady. This is shown in Fig. 52. The lines of force of B will in this case have the same positive direction as those of A, showing that the induced current in B is in the same direction as the original current in A.

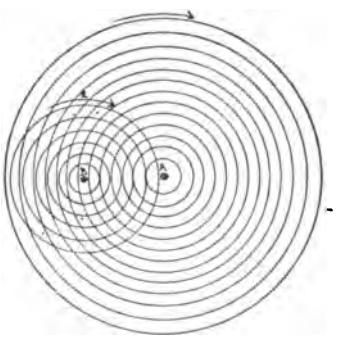


FIG. 52.—Illustrating Reversal of Current Due to Induction.

The following figures, 53, 54, 55, and 56, are intended to show how in one case the direction of the wave lines, the lines of force, are in the opposite direction to the original lines and in the other case how they are in the same direction.

Fig. 53 represents a wave as emanating from A and travelling in the direction of its normal, shown by the long arrow towards B; that is, it is expanding. The wave front on the left is shown as striking an obstacle B and its onward motion carries the outer part onward, the part near the obstacle being retarded. The arrows show the positive direction of the lines due to the current in A. The wave front bends around B until it is torn apart, as it were, when the wave front unites, with its positive direction the same

as before, leaving a small wave around *B* in the opposite direction, as shown by Fig. 54, this small wave then expanding around *B* as the other did around *A*, but with diminished energy. Each succeeding wave from *A* is acted upon in the same manner, forming a succession of waves around *B*.

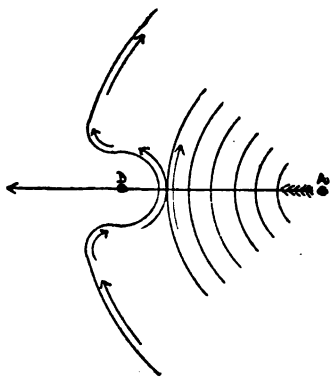


FIG. 53.

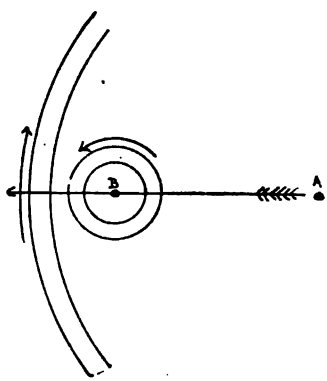


FIG. 54.

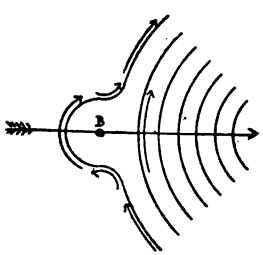


FIG. 55.

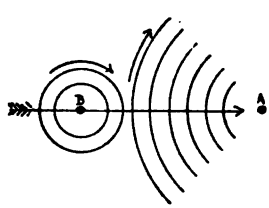


FIG. 56.

Fig. 55 represents a wave as emanating at *A* and travelling in the direction of its normal, shown by the long arrow; that is, it is collapsing on *A*. The wave front on the left is shown as striking an obstacle *B*. Similar to the above, it is shown that the small wave set up around *B* is of the same direction as the collapsing wave. This small wave expands around *B* as shown in Fig. 56, inducing a current that is in the same direction as the weakening current in *A*. Each succeeding wave collapsing on *A* is acted upon in the same manner, forming a succession of waves around *B*.

If both A and B have currents from some outside source flowing in them, any change in one will produce a change in its field which will react on the other, either increasing or decreasing its current as long as the change is taking place.

Coefficient of Mutual Induction.—This is defined as the number of lines of force *mutually* embraced, or are common to both circuits, when each carries unit current. If L_1 is the coefficient of induction of the first coil, called the *primary,* and L_2 of the second, called the *secondary,* then the coefficient of mutual inductance is

$$M = \sqrt{L_1 L_2}.$$

The coefficients of induction of each coil depends on the permeability of the surrounding medium, so, therefore does M, and the introduction of an iron core to the interior of one coil will greatly increase M.

Mutual induction plays an important part in the principle of many electrical devices for the conversion of E. M. F. into higher or lower values. Prominent among these devices are Alternating Current Transformers and Induction Coils.

Principle of Transformers.

As in the case of self-induction, the mutual induction between two closed circuits will be greatly increased by making the conductors in the form of helices and winding them on some strongly magnetic material like soft iron, and bringing the turns on one close to those of the other. If under these conditions a rapidly alternating current be sent through one coil, it will produce a rapid expansion and contraction of its field which will produce a corresponding change in the current in the other coil. By making one coil of a great many turns of very fine wire, a very high E. M. F. can be produced. By varying the size of the wire and number of turns in the two coils, a convenient method of changing the E. M. F. of a given source of supply is at hand.

The elementary form of transformer consists of a closed magnetic circuit, on which are wound the two coils, one called the primary; the other, the secondary, as shown in Fig. 57.

A and B are the terminals of the primary and C and D of the secondary. The primary may consist of many turns of fine wire to receive a small current at high E. M. F. and the secondary of a few turns of thick wire to give out a larger current at low pressure. Such a transformer would be called a "step down" transformer. If wound in the opposite sense, it would be called a "step up" transformer.

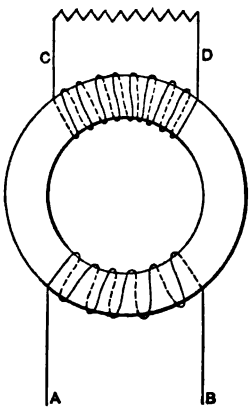


FIG. 57.—Typical Transformer.

Apart from the small losses in transformation, the *input* is equal to the *output*, and if V is the terminal E. M. F. and C the current of one coil and V_1 and C_1 of the other, then

$$VC = V_1C_1.$$

E and E_1, the total E. M. F's. induced in each coil are directly proportional to the number of turns in the two coils.

The relation between the voltages at the terminals is given by the following expressions:

$$V = E + Cr \text{ (for primary)},$$
$$V_1 = E_1 - C_1r_1 \text{ (for secondary)},$$
$$\frac{E}{E_1} = k \text{ (a constant depending on the relative number of turns)}$$

from which the relation of V to V_1 may be found.

$$V_1 = \frac{V}{k} - \left(\frac{r}{k^2} + r\right)C_1.$$

Induction Coils.

In the ordinary induction coil, it is not usual to use an alternating current, but a continuous current from a few cells, the change in the magnetic field of the primary coil being caused by making and breaking the circuit. The primary coil is connected in series with a condenser, which has the effect of making the "*break*" more rapid and opposing the current at "*make*."

The connections of a simple induction coil circuit are shown in Fig. 58.

A represents the magnetic core around which are wound the two coils, the primary from the battery *B;* the secondary being wound over it, and carefully insulated. The terminals of the secondary coil are shown at *a, b.* The continuous current from the battery is interrupted at *I,* a pivoted conductor, which makes contact either with *K* or is drawn away from it towards the core *A.* When *I* makes contact with *K* and current from the battery flows around the primary coil, *I* is attracted to the core, breaking the circuit at *K.* As soon as the circuit is broken, the core ceases to be magnetic and

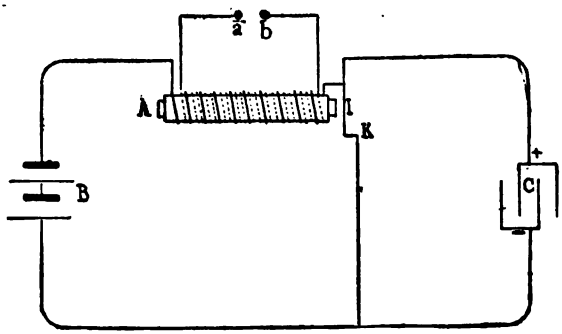


FIG. 58.—Circuit of Induction Coil.

I makes contact again with *K,* when the circuit is re-established. This constitutes the make and break and the alternating field produced in the core induces an alternating current in the secondary coil, the current being manifested by a spark jumping from *a* to *b.*

The E. M. F. of the secondary coil depends on the rate of change of the magnetic field of the primary coil, as $E = -\frac{dN}{dt}$, where N is the number of lines of force. N depends on the primary current and t on the number of makes and breaks. When the interrupter *I* is attracted towards the core and the circuit is broken, the induced current produced by the break would ordinarily cause a spark to jump from *I* to *K,* but by introducing the condenser in circuit, this extra induced current flows into it, charging the upper plate positively, the lower, negatively. These charges

immediately recombine, flowing through the primary and battery, thus reducing the battery current at the time the circuit is again made, and demagnetizing the core. This action increases the time of the "*make*," while reducing the time of the "*break*," making the latter quicker and sharper, the result of which is a high E. M. F. in the secondary. The terminals *a* and *b* can be so arranged that the spark due to break can jump across, while that due to make cannot, thus making a steady stream of sparks.

Induction Coils for Creating Electric Oscillations.—In most systems of wireless telegraphy an induction coil is used in the creation of electric oscillations necessary for the formation of electromagnetic waves, and the following description is of a type suitable for such work:

Induction coils are known by their size, thus a 10-inch coil means that it will produce in air a spark 10 inches long between the terminals of the secondary coil. A coil of the above size would consist of 300 to 400 feet of insulated copper wire, wound around an iron core consisting of a bundle of soft iron wires about 2 inches in diameter. The secondary would consist of 12 to 15 miles of very fine double-covered silk copper wire, depending on the diameter, making 45,000 to 50,000 turns, wound over the primary. The winding of the secondary is made in a large number of sections, each section prepared separately and each carefully insulated with paraffin and discs of shellaced paper. A large number of such sections varying from 100 to 500 are slipped over a thick ebonite tube, inside of which is the primary coil and iron core.

When the coil is in operation great differences of potential exist in the coils of the secondary and this must be so wound that no two parts, which are a great difference of potential, are near together. There must also be perfect insulation between the primary and secondary coils, and it is usual to have them separated by a tube of ebonite at least half an inch thick covered with a layer of paraffin an inch thick.

When the sections of the secondary coil are assembled on the insulating tube they are compressed and immersed in molten paraffin. This is done on a former, after which the whole secondary winding is enclosed in a cylinder of ebonite and thick ebonite cheeks

are fitted on the ends of the ebonite tube on which the secondary is wound.

The completed coil may be then enclosed in a wooden box which is filled with insulating oil or filled in solid with paraffin, the ends of the secondary being brought out through ebonite tubes.

If the coil is to be used with an interrupted continuous primary current, a condenser is placed across the point of rupture of the primary current, its action being previously described.

In some forms of induction coils, the primary is wound in sections and the ends of each brought out in such a manner that the various sections can be joined in series or in parallel so as to vary the resistance and inductance of the coil, as well as the effective number of turns.

CHAPTER IX.

ELEMENTARY THEORY OF THE ELECTRIC GENERATOR.

An electric generator, or simply a generator, is a dynamo electric machine constructed for the purpose of converting mechanical energy into electric energy by the induction of E. M. F. in a closed coil moved in a magnetic field.

Referring to the chapter on the Derivation and Definition of Units, the C. G. S. unit of E. M. F. is defined to be *that E. M. F. produced by the cutting of a magnetic field of one gauss intensity by one centimetre of the conductor moving at a velocity of one centimetre per second.*

In Fig. 59, the straight wire AD is fitted to slide along the portions AB and CD and to form portion of a closed circuit $ABCD$. The whole circuit is placed in a uniform magnetic field of intensity H, perpendicular to the plane of the paper with the positive side on this side of the paper.

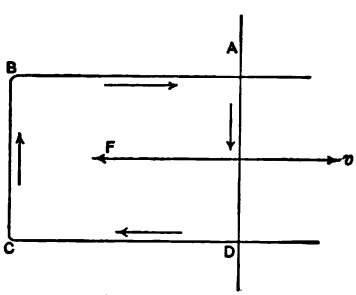


FIG. 59.—Illustrating the Principle of the Generator.

If AD is moved to the right at a velocity of v centimetres per second, there will be an E. M. F. induced in the conductor which will create a current in the direction indicated by the arrows. If the length of AD is l centimetres, then, according to the definition of E. M. F., the number of absolute volts induced will be

$$E = Hlv.$$

The E. M. F. induced produces a current which is urged across the magnetic field; the C. G. S. unit of current existing *when each*

centimetre of its length is urged across a magnetic field of unit intensity with a force of one dyne.

From Lenz's law it is seen that the work done in producing the induced current opposes the action which produces it, and the total force urging the conductor across the magnetic field is

$$F = HlC \text{ dynes.}$$

The work done on the conductor against this force is Fv ergs per second and which must be equal to the electric work produced, or

$$Fv = HlCv,$$

or

$$\text{work done} = EC \text{ ergs per second}$$
$$= EC \text{ watts.}$$

In the generator, then, work is supplied by an external agency moving a conductor across a magnetic field and continually overcoming a force which tends to stop it. The greater the current induced or the greater the intensity of the field, the greater the force to be overcome and the greater the power necessary to be supplied. Due to the mechanical construction of the generator, the force overcome is a tangential pull applied at the radius of the armature, and the product of the two factors, *force* and *radius,* is called the **drag** on the conductors. If the conductor is supplied with an E. M. F. this drag on the conductor would cause the conductor to move in the opposite direction and the generator then becomes a motor.

Expression of Induced E. M. F.—In t seconds the wire AD moves over a space equal to vt and cuts lvt square centimetres. If the intensity is H; or, in other words, if there are H lines of force per square centimetre, the total number of lines cut is $Hlvt$, and since $E = Hlv$

$$E = \frac{N}{t},$$

where N = total number of lines or magnetic flux.

This shows that the induced E. M. F. is equal to the rate of cutting of the lines of force, or the *E. M. F. in C. G. S. units is equal to the number of lines of force cut per second.*

Induced E. M. F. in a Closed Coil.

In Fig. 60, N and S represent the north and south poles of a magnet, either permanent or electromagnetic, producing a magnetic field that is represented by the lines running from one to the other, the arrowed heads representing the positive direction of the lines of force. In this field and lying at right angles to the lines of force is a rectangular loop of wire, its open ends being connected to a voltmeter, thus making a closed circuit, and capable of rotation round an axis represented by the broken line.

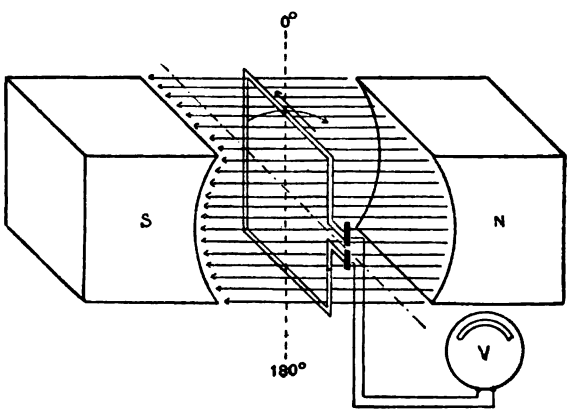


FIG. 60.—Induced E. M. F. in a Closed Coil.

As this coil lays at rest in the field there is no reaction between them, and the voltmeter indicates zero. In this position, being at right angles to the lines of force the greatest number of lines thread through the loop. As the coil is revolved as shown by the curved arrow to the right, the number of lines that thread through the coil constantly diminishes in the proportion of the angle turned through from 0°. If N is the total number, then at any angle θ, the number that threads through the loop is $N \cos \theta$, and at 90°, or when the loop is laying parallel to the lines, the number is a minimum. As soon as the coil is revolved so as to cut the lines of force, an E. M. F. is generated and it will be indicated on the

voltmeter and if the coil is turned at a constant speed this E. M. F. will increase until the 90° position is reached when it is a maximum. Now applying the laws of induction, we see in what direction the resultant current is; for imagine the eye in the face of the north pole and looking along the positive direction of the lines of force. The voltmeter end of the coil will then be on the left hand. As the coil turns, the number of lines of force is decreased, and a decrease means a direct current or clockwise current when looking along the positive direction of the lines of force. In this case, the current would flow in the direction indicated by the straight arrow. As the coil passed the 90° position, there would be an increase in the number of lines, which should produce an inverse current, or anti-clockwise, as viewed by the same observer, but now he is looking at the other side of the coil, or what was the top is now the bottom, so, though it is anti-clockwise as he views it, it is really in the same direction in the coil as before. The E. M. F. will gradually decrease from 90° to 180°, where it will again be zero, and this will be indicated on the voltmeter.

It must be remembered that the E. M. F. is not only proportional to the number of lines cut, but to the rate at which these lines are cut. At the 0° and 180° position, the greatest number of lines are being cut, but there the E. M. F. is least, and at 90° the lines thread through the coil at the greatest rate, at uniform speed, and here the E. M. F. is greatest, or the number of lines threading through at any time is $N \cos \theta$, and the rate of cutting is $d(N \cos \theta) = -N \sin \theta$, which is in accordance with the third law of induction, the minus sign indicating the decrease. The sine function varies from 0 to unity, or the E. M. F. at 0° is $\sin 0° = 0$ and at 90° is $\sin 90° = 1$, or proportional to these limits. Continuing the motion from 180° to 270° results in a direct current, or clockwise, and this is in direct opposition to the current in the first half of the revolution. From 270° to 0°, the current is inverse as viewed from the same place, but the coil now being turned over is in the same direction as from 180° to 270°.

The final result then of one complete revolution of the coil is generation of E. M. F. and induction of current, starting at 0° with both a minimum and increasing to a maximum at 90°, then

decreasing again, the current being in the same direction to 180°. From this point everything is reversed, the E. M. F. and current increases to a negative maximum, and then decreases to 0° as the original position is occupied. This result is both in accordance with the theory as deduced from the laws of induction, and is actually shown on the voltmeter, on passing the 180° position, the deflection of the needle being reversed.

As the E. M. F. is proportional to the rate of cutting, the faster the coil is turned, the greater will be the maximum E. M. F., and greater in proportion at any intermediate position.

It may be noticed that it is stated that the lines of force thread through the loop formed by the coil and the number of lines of force that do this first increase and then decrease. This is simply a convenient way of expressing the fact that the lines of force are actually cut by the coil in its revolution, and the mere fact that the lines of force thread through the loop would not necessarily mean a generation of E. M. F. It should also be noticed that the sides of the coil, the up-and-down connections, although they pass through lines of force, do not alter the number cut, so there is no E. M. F. due to these parts of the coil; they simply act as conductors to complete the circuit.

Induced E. M. F. in a Closed Surface.—If this coil were replaced by a thin sheet of conducting material, the action and resulting current would be the same, with the exception that every part of the thin sheet would cut lines of force and the current would circulate in all parts as small eddies, having a resultant effect of one large current, and would be reversed in exactly the same way as in the case of the coil. In this case also, there would be a real increase and decrease in the number of lines that pass through the sheet as well as an increase and decrease in the number of lines cut.

Curve of E. M. F.

As the E. M. F. generated in the preceding demonstration increases from 0 to a maximum, then decreases to 0, and increases again to a negative maximum and then again to 0, there must be some constant relation between the E. M. F. generated and the

time of revolution. The relation is represented by the curve of sines, as the E. M. F. is proportional to $d(N \cos \theta) = -N \sin \theta$, and θ depends on the rate of revolution. The curve of sines is the resultant motion of a particle that is acted on simultaneously by two motions, one a simple harmonic motion in a straight line and the other a uniform motion at right angles to it, and on account of its identity with the curve of E. M. F. its construction is given in Fig. 61.

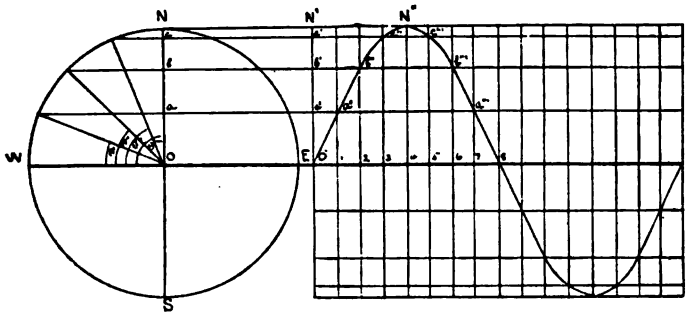


FIG. 61.—Curve of E. M. F.

Curve of Sines.

If a particle W revolves in the circle $NESW$ at a uniform rate, in equal times, it will pass over equal arcs of the circle, and if the points at which the particle arrives at the end of equal intervals of time be projected on a diameter of the circle, the motion of these points on the diameter will constitute a simple harmonic motion.

The curve of sines has been defined as the resultant motion of a particle that is acted upon simultaneously by two motions, one a simple harmonic motion and the other a uniform motion at right angles to the simple harmonic motion.

The simple harmonic motion is represented as taking place in the line NOS, the points a, b, c, and N being the projections of the points arrived at in the circle by a particle that is uniformly revolving in it, the equal intervals of time in this case being 1-16 of the time of one revolution. The uniform motion is taking place in the line WOE. In equal times the uniform motion carries the

particle to the right equal distances, and the equal distances between the vertical lines are arbitrarily chosen to represent the distance carried.

Let the particle be at o'; it is acted upon by two motions, a simple harmonic motion in the line $N'O'S'$ and the uniform motion in the line WOE. If the particle was acted upon by the simple harmonic motion alone, in 1-16 of the time of one period, it would be at a'. If acted upon by the uniform motion alone, in the same time corresponding to 1-16 of a period of the simple harmonic motion it would be at 1. As it is acted upon simultaneously by these two motions, in 1-16 of a period, it would be at a'', describing the path $o'a''$. Similarly in a time represented by 2-16 of a period, in its simple harmonic motion it would be at b', and due to the uniform motion, it would be at 2, and as they act together, it would be at b'', describing the path $o'a''b''$. Similar reasoning will show how the points $c''N''c'''b'''a'''$, 8 are determined, and a curve drawn through these points will show the resultant path of the particle. As the particle in its simple harmonic motion passes through O', going towards S', the uniform motion still acting, the part of the curve below the median line is described. When the particle has completed 16-16 of its period in its simple harmonic motion, it has been carried to the right 16 equal distances, and the particle is in a position to repeat the described curve.

Properties of the Curve.—The ordinates of the curve are proportional to the sines of the angles described by the particle in its uniform motion in the circle, the motion of this particle representing the motion of the coil in the elementary dynamo. $a''1$ is proportional to sin θ', $b''2$ to sin θ'', etc. If the height of the middle ordinate $N''4$ is unity, as the sine of θ'''' or 90° equals 1, the heights of the other ordinates will represent, in terms of the middle ordinate, the sines of the angles formed at the center of the circle.

The abscissæ are proportional to the time during which the uniform motion acts, and which time being proportional to the arc of the circle swept over in the same time, is proportional to the sines of the angles thus described. As the ordinates are pro-

portional to the sines of the angles, and the time to the sines of the angles, the equation of the curve must be $y = \sin x$, the axis of Y representing sines and the axis of X, time. The area included between one quarter of the curve and the median line is

$\int_0^{\frac{\pi}{2}} y dx$ or $\int_0^{\frac{\pi}{2}} \sin x dx$, or area $= -\cos x \Big]_0^{\frac{\pi}{2}} = -(0-1) = 1.$

As the length of the median line for a quarter of the curve is $\frac{\pi}{2}$, the average value of the ordinates must be the area divided by the base or $\frac{1}{\frac{\pi}{2}} = \frac{2}{\pi}$; or, in other words, the average value of the sine function from 0° to $\frac{\pi}{2}$ must be $\frac{2}{\pi}$, or 7-11. Also the average value of the heights of the ordinates must be $\frac{2}{\pi} \times$ the height of the maximum ordinate.

In one revolution then of the coil in the elementary dynamo, the average E. M. F. is 7-11 of the maximum E. M. F.

The Act of Commutation.

It has been shown how a coil revolved in a magnetic field has an E. M. F. generated in it, and a current induced, and how in one revolution the current grows to a maximum, then decreases to a minimum, and then has the direction of the current reversed and the phenomena repeated. In continuous-current dynamos it is necessary that there be some means provided by which the current is made to flow in one direction in the external circuit, while it is reversed in each revolution in the internal circuit. This is effected by means of a *commutator* and the operation is called the *act of commutation.* Each end of the coil is secured to a segment of a circle, made of some conducting material, the segments being separated by air gaps or some insulating material. These segments taken together constitute the commutator, on which rests the brushes, which collect the current for the external circuit. Just how the reversal is effected will be explained by small sketches showing the position of the coil in different stages of the revolution.

Fig. 62 represents the loop lying in the magnetic field between the pole pieces *N* and *S*, the lines of force running from *N* to *S*, and being omitted for sake of clearness. This loop is perpendicular to the lines of force and in the 0° position, the brushes being shown as just touching both segments of the commutator and connected to the external circuit marked *R*. One-half of the loop is shown as a double line, being connected to its segment of the commutator, also double; the other half of the loop with its segment being shown as shaded, and they will be referred to as *double* and *shaded.*

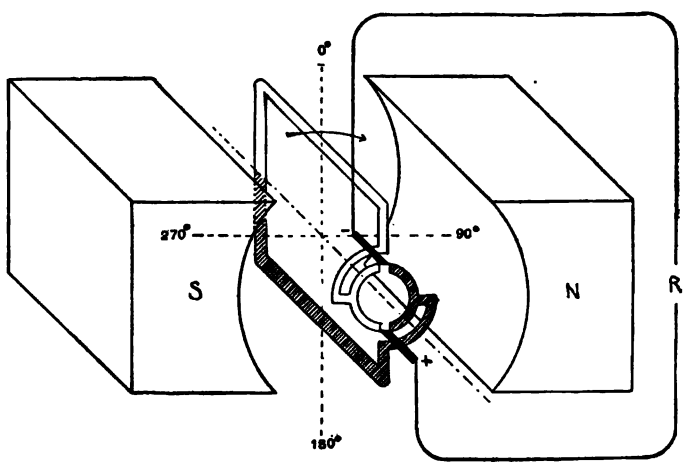


FIG. 62.—Act of Commutation, Coil at 0° Position.

In this 0° position, there is no E. M. F. generated and no current induced. As soon as the coil is revolved in the direction of the curved arrow, E. M. F. is generated, and by the laws of induction current is induced and flows from double to shaded in the internal circuit, and from shaded to the external circuit through the + brush and from the external circuit to double through the — brush. This condition is shown in the next figure.

In Fig. 63 the pole pieces have been removed but are supposed to be in the same position as in the first figure. This represents the loop in a position shortly after revolution has commenced, a

position a little in advance of the 0° position. A direct current as viewed by an observer looking along the positive direction of the lines of force is induced, or to the observer it is clockwise and flows from *double* to *shaded* in the internal circuit, from shaded to the external circuit through the + brush and from the external circuit to double through the — brush. The direction of the currents is indicated by the arrow heads. The brushes of course remain stationary. When the revolving coil passes the 90° position, the

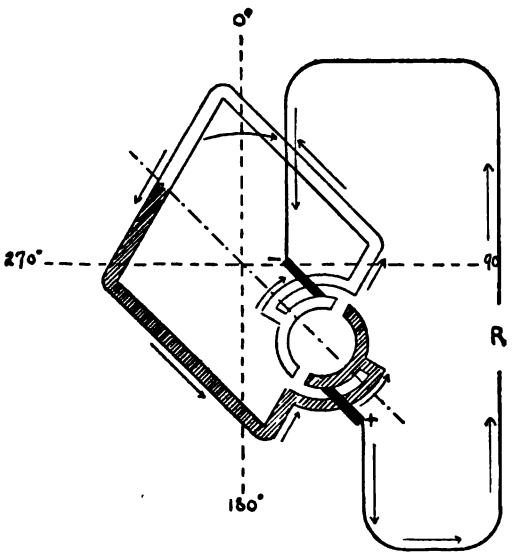


FIG. 63.—Act of Commutation, Coil Passed the 0° Position.

shaded half is then uppermost, and there is an inverse or anti-clockwise current as viewed by the same observer, as there is now an increase in the number of lines of force cut, but the coil being turned over a direct current on one side and an inverse on the other makes the current in one real direction, and from 0° to 180°, the current in the internal circuit will be from double to shaded.

This position of the loop (Fig. 64) shows it just before the 180° is reached. The current in the internal circuit is still from *double* to *shaded* and the external current remains as before. The current

is weakening as this position is reached and when it reaches the 180° position, it will be the same as in the first figure, with the exception that the coil is simply turned over and the current both in the internal and external circuits has died out, and the brushes will just touch both segments of the commutator. Further revolution from the 180° position will reproduce the phenomena of induction as in the 0° position with the exception of the coil being turned around. Following from 180° is shown in the next figure.

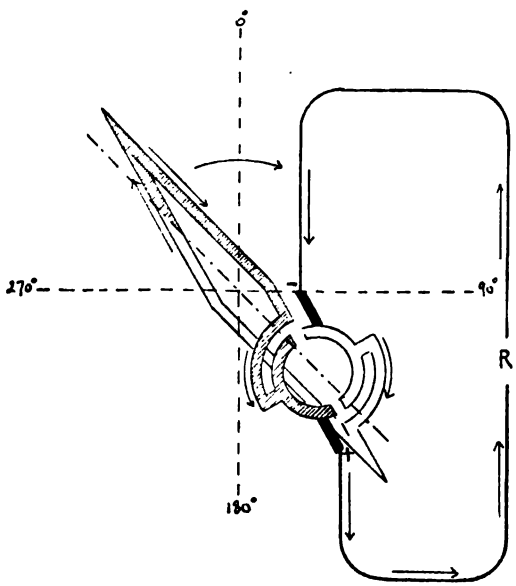


FIG. 64.—Act of Commutation, Coil Approaching the 180° Position.

Fig. 65 represents the coil just after the 180° position is reached. There is now again a decrease in the number of lines of force cut, and a direct current for the same observer, but now the coil being turned half way around, the current flows from shaded to double in the internal circuit, from double to the external circuit through the + brush, and from the external circuit to shaded through the — brush. Thus it is seen that though the actual direction of the current in the coil is reversed, by means of the commutator the

direction of the current in the external circuit remains the same as before, and as far as its direction is concerned, it is continuous, which is the sole object of the commutator. The current will increase in intensity until the 270° position is reached. From that position to the 0° or 360° position, there is an increase in the number of lines of force cut, or an inverse anti-clockwise current as viewed by the same observer, but what is now clockwise will

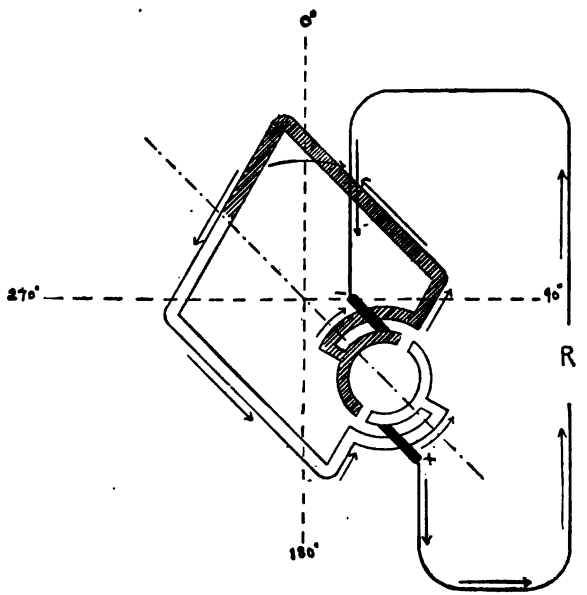


FIG. 65.—Act of Commutation, Coil Passed the 180° Position.

then be anti-clockwise and the real direction of the current in the internal circuit will be the same from 180° to 360°.

Fig. 66 represents the loop just before the 0° or 360° position is reached. The current is now anti-clockwise as explained under the previous figure, but is still from shaded to double. The current is decreasing as the 360° position is approached until that is reached when the current has died out entirely, and the loop is in its original position, each brush just touching both segments of the commutator.

To summarize then: The current is nothing at 0°, then gradually approaches a maximum in both circuits until 90° is reached, then decreases to a minimum and becomes nothing at 180°, both currents having died out. From 180° both currents increase, the direction of the current in the internal circuit having been reversed, while the current in the external circuit remains the same as before. This increase continues until 270° is reached when

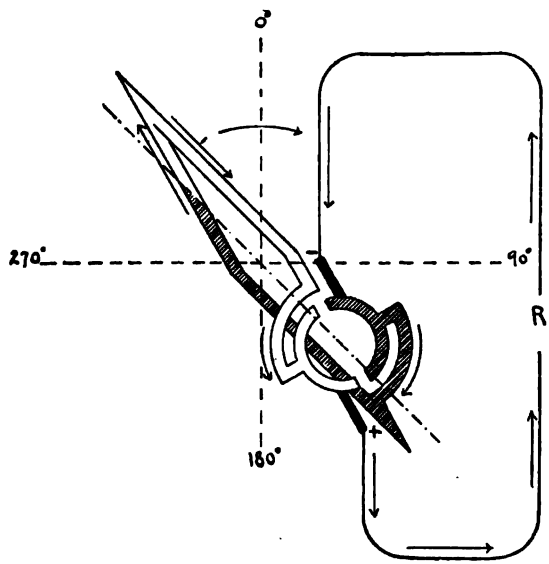


FIG. 66.—Act of Commutation, Coil Approaching the 360° Position.

both currents are at a maximum again and then decrease of both currents takes place until the original position is occupied when both currents have completely died out. Further revolution of the coil repeats the phenomena.

The Generation of an Increased and Steady E. M. F.

It has been seen that a simple rectangular turn without a commutator when revolved in a magnetic field so as to cut lines of force gives rise to a fluctuating E. M. F., which in its complete

revolution is represented by the ordinates of the curve of sines, as shown by Fig. 67. Two revolutions are represented.

If the coil is fitted with a commutator, the negative ordinates of the curve are commuted into positive ordinates as shown in Fig. 68.

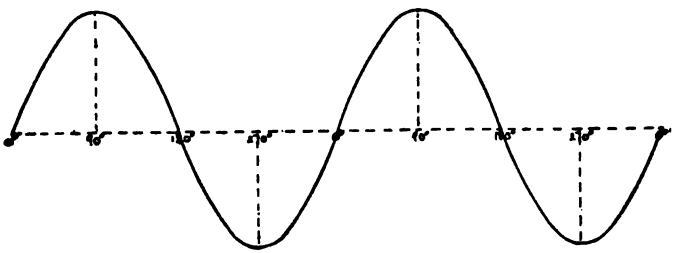


FIG. 67.—Curve of E. M. F. Before Commutation.

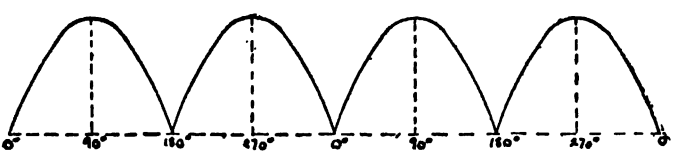


FIG. 68.—Curve of E. M. F. After Commutation.

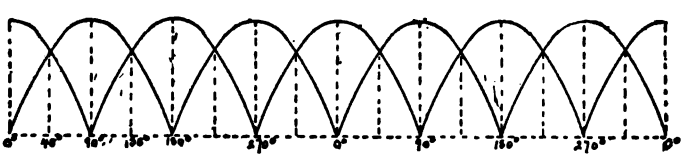


FIG. 69.—Curves of E. M. F. Due to Two Coils.

If, in addition to the simple turn, there is another turn placed at right angles to the first and connected to its own segments of the commutator, and entirely independent of the first turn, it will exhibit the same phenomena and give rise to the same curve of E. M. F. with the exception that it will differ in phase by one-quarter of a period, or the curves will differ in their maxima and minima by 90°. The result of two turns 90° apart is shown by Fig. 69, showing when one is in position of maximum cutting of lines of force, the other is in the position of minimum cutting.

If these two turns be connected in series with one another, or in other words, if the same length of conductor in the two turns be made into one coil with the two turns at right angles to each other, then the curve of E. M. F. in its entirety ceases to be the curve of sines, but the E. M. F. at any point is equal to the sum of the individual E. M. F's. at that point due to each turn alone.

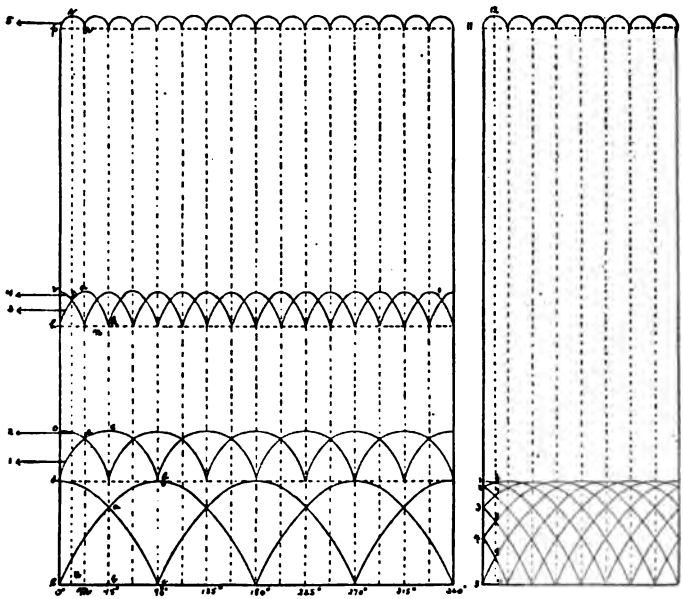


FIG. 70.—Curves of E. M. F. Showing Superposition.

In this case, the maximum E. M. F. would be at 45°, 135°, 225°, and 315°, and the minimum at 0°, 90°, 180°, 270°, and 360°.

The result of superimposing the two curves formed by each turn of the coil, the turns being at right angles to each other, is shown in curve 1 of Fig. 70. The height of the ordinates at 0° and 90° of curve 1 is equal to the height of the ordinates at 0° and 90° of the original curve of E. M. F., these being shown at the bottom of the left-hand portion of the diagram. The height of the ordinates at 45°, 135°, 225°, and 315° is each equal to the sum of the

ordinates at 45° of the original curves, or *bc* of the curve 1 is equal to $2 \times ab$.

Curve 1 then represents the E. M. F. due to one coil consisting of two turns at right angles to each other, connected in series, and has resulted in a mean E. M. F. of twice the original mean E. M. F.

If another coil consisting of two turns at right angles to each other, and connected in series, be placed at equal distances between the turns of the first coil, it will give rise to another curve similar to 1, marked 2, having its maximum value where the other is a minimum and vice versa. If these two coils, or four turns, be connected in series, the resulting curve of E. M. F. will be curve 3, *he* being equal to $oe + de$, and $nm = ne + em$, or $2 \times em$.

Curve 3 then represents the E. M. F. due to one coil consisting of four turns at angles of 45° to each other, all four turns connected in series, and has resulted in a mean E. M. F. of twice the value of curve 1, and four times the value of the E. M. F. due to one turn.

If again another coil consisting of four turns at 45° to each other, and connected in series, be placed at equal distances between the turns of the other coil, it will give rise to another curve similar to 3, and marked 4.

If these two coils, or eight turns, be connected in series the resulting curve of E. M. F. will be curve 5, *pe* being equal to $ve + he$, and *su* being equal to $st + tu$ or $2tu$.

Curve 5 then represents the E. M. F. due to one coil consisting of eight turns, at angles of $22\frac{1}{2}°$ to each other, all eight turns connected in series, and has resulted in a mean E. M. F. of twice the value of curve 3, four times the value of curve 1, and eight times the value of the mean E. M. F. due to one turn.

This process shows that the more conductors there are in series, the higher and steadier the E. M. F. and a point would eventually be reached when the curve would approximate a straight line, and this is really in fact the theoretical process of building up a drum-wound armature.

The same steadiness without the increased E. M. F. would be observed if the eight turns, or sixteen cutting conductors were each connected to their segments of the commutator without in any way being connected to one another. The resulting curves are

shown in the right-hand lower portion of the diagram, and it is seen that the E. M. F. is as nearly continuous as in the first case, but the E. M. F. is that due to one turn. If again these were all connected in series as before, the resulting curve of E. M. F. would be obtained at any point by addding together all the ordinates of the different curves at that point, and of course it should give the same curve as in the first case, where the additions take place separately. The height of the ordinate 5.11 is equal to $1.5 + 2 \times 2.5 + 2 \times 3.5 + 2 \times 4.5$, and 10.12 is equal to $2 \times 6.10 + 2 \times 7.10 + 2 \times 8.10 + 2 \times 9.10$.

Curve of Total E. M. F.

The curve of sines represents by the heights of its ordinates the E. M. F. at any instant of a single turn of conducting material revolved in a magnetic field in terms of the maximum ordinate as unity. The total E. M. F. due to the same turn in one revolution is the sum of all the ordinates, that is, the total E. M. F. from 0° to 45°, for instance, is the sum of all the ordinates from 0° to 45°, or is represented by the sum of all the sines of the angles from 0° to 45°. In other words, it is the integration of the equation of the curve from 0° to the point considered, or

$$\int_{0^\circ}^{x^\circ} \sin x dx = -\cos x \Big]_{0^\circ}^{x^\circ}$$

The curve of total E. M. F. from 0° to 360° is represented by Fig. 71.

Armature Cores.

So far in the consideration of the physical theory of the generator, the turn of wire was supposed to be revolved between the poles of a magnet, permanent or temporary, in the field produced by the poles, and without any mechanical connection with any other revolving part. It must necessarily be wound on some kind of support and to this support the general name of core is applicable. As far as mechanical considerations go, this core might be made of wood or brass or hard rubber, but electrical considerations show that it should be of some magnetic material, in order that the lines

of force may be drawn to and through it, or as it has been seen under *magnetic circuit,* in order that the reluctance of the magnetic circuit may be reduced. For a given magnetomotive force, due to the ampere turns of the field windings, the total number of lines, or flux, depends on the magnetic resistance, and the smaller this can be made, the greater will be the flux. The conductors must cut the lines of force and to do this they must thread through one side of the core and out the other. If the core were of some non-magnetic substance, the lines of force would tend to go around it rather than through it, its permeability being less than that of air,

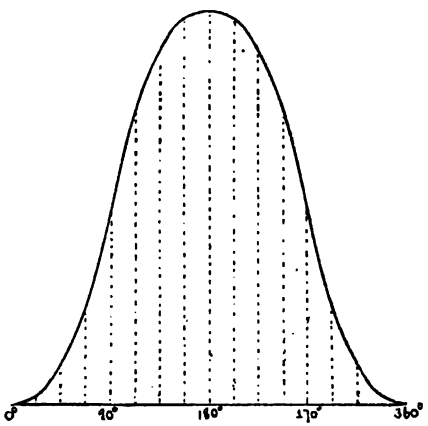


FIG. 71.—Curve of Total E. M. F.

the lines of force cut by the conductors being much reduced. Where a magnetic core is used, the magnetic circuit consists of the field frame, the pole pieces, the air gaps between the pole pieces and armature core, and the core itself. This shows, too, that the air gaps should be as small as possible, and the pole pieces should have a cross-section at least equal to the smallest cross-section of the magnetic circuit.

Eddy Currents.—The core, being magnetic, while revolving in the magnetic field is subject to the same laws of induction as the conductors themselves, and would have induced in its mass currents which would flow around and through it, and in any one cross-

section they would flow in the same direction. They follow the paths of least resistance in the core, thus giving rise to innumerable little complete circuits, to which the name of *eddy currents* is given. The effect of these currents is to heat the core, and being brought into existence by the power which revolves the armature they represent a distinct loss of energy. It is remembered that the induced current has a direction which is at right angles to the magnetic lines, and if the circuit of the eddy currents can be shortened in that direction their waste will be reduced. This is effected by cutting the armature core in thin slices in a direction parallel to its direction of rotation and to the lines of force and perpendicular to the direction of the induced currents. The thin slices or laminations are put together, being insulated one from the other, the effect being to reduce the eddy currents without increasing the magnetic resistance of the circuit. Any through connections there may be for holding the laminations together will have induced currents in them, but it is usual to have them well inside the core, where the field is weakest.

Calculation of Induced E. M. F.

The preceding curves show that an increased E. M. F. is produced by connecting up the single coils in series, so as to make one closed coil of many turns. The number of conductors on the armature then becomes one of the factors that determine the value of the E. M. F. generated. Under the definition of volt, it was seen that it was the E. M. F. induced when a conductor moves in a magnetic field at such a rate that it cuts 10^8 lines of force per second. The number of lines of force is then another factor of the generated E. M. F. The effect of cutting lines of force may be increased by increasing the speed at which the conductor moves, thus if a conductor moves at such a rate as to cut 2×10^8 lines of force per second, it will generate 2 volts and so on.

The three factors that determine the E. M. F. in a dynamo are (1) *the number of cutting conductors;* (2) *the number of lines cut;* (3) *the speed at which the lines of force are cut.*

Starting with the elementary coil of the drum armature in the 2-pole dynamo in a plane at right angles to the lines of force, it

embraces the total number of lines, which may be represented by N. If this rectangle or coil makes one revolution per second there are $2N$ lines cut per second by each limb of the coil, because each limb cuts the whole number of lines in each half revolution. If the coil makes n revolutions per second the number of lines cut per second by each limb is $2Nn$. If there are Z conductors all the way around the armature, or Z limbs, there are $\frac{Z}{2}$ limbs in series from brush to brush, or the number of lines cut by $\frac{Z}{2}$ limbs is $\frac{Z}{2} \times 2Nn = NZn$, or the average E. M. F. induced is $\frac{NZn}{10^8}$ volts, where

N = total number of lines of force,
Z = total number of conductors around the armature,
n = number of revolutions per second.

In drum armatures, the number of limbs is twice the number of coils in each section, whereas in the ring armature, the number of limbs is equal to the number of coils in each section, and the same formula is applicable to both armatures. Z always represents the number of conductors counted all the way around the armature.

The average E. M. F. may be expressed in terms of angular velocity by putting $\omega = 2\pi n$ where ω = angular velocity and then

$$E = \frac{\omega}{2\pi} NZ.$$

In a time t, the angle θ turned through would be $2\pi nt$ and the number of lines enclosed by the rectangle at the angle θ turned through from zero would be $N \cos \theta$, and the rate of cutting would be the rate of $N \cos 2\pi nt = 2\pi nN \sin \theta$. The average of sin $\theta°$ between 0° and 90° is $\frac{2}{\pi}$, so the average

$$\text{E. M. F.} = 2\pi nN \times \frac{2}{\pi} = 4nN.$$

The number of rectangles is $\frac{1}{2}Z$ and the number of conductors in series from brush to brush is $\frac{1}{2} \times \frac{1}{2}Z$ or the final average E. M. F. $= 4 \times \frac{1}{4}ZNn = NZn$ as before.

Fundamental Equation of the Direct-Current Generator.—The above equations are adduced to apply to bipolar machines, but a more general solution for the value of the induced E. M. F. is given.

Let N = the number of magnetic lines that enter the armature from each north pole and leave at each south pole of the field magnets,

p = number of field poles,

Z = number of conductors on the outside of the armature,

p' = number of parts in parallel between brushes,

n = number of revolutions of armature per second.

In $\frac{1}{pn}$th of a second the armature will move the distance between two poles, or between the brushes and in this time will cut N lines of force. The conductors are then cutting at an average rate equal to $N \div \frac{1}{pn}$, or pnN lines of force per second. The average E. M. F. from brush to brush per conductor is pnN at any instant.

The number of conductors in series in each path between the brushes is $\frac{Z}{p'}$ and since the average E. M. F. per conductor is pnN, the E. M. F. between the brushes is $pnN \times \frac{Z}{p'}$, or

$$E = \frac{pnNZ}{p'}.$$

This equation applies to bipolar or multipolar machines, and ring or drum armatures with any kind of winding, the above expression giving the E. M. F. between the brushes in absolute units.

Points of Design.—In generators designed for use with direct-connected motive-power as with sets used on shipboard, the number of revolutions of the armature is limited by the speed that can be given to the engine and this is necessarily low. Increasing the number of conductors in series on the armature results in higher E. M. F., but at the same time adds to the resistance and to the self-induction, both of which are objectionable. Increasing the area of the armature conductors or making the core more massive

increases the number of lines cut, and this is one of the features of modern dynamos, the cores being very large and the conductors few and heavy. The greatest factor of the E. M. F. is undoubtedly the magnetic field, and this is the most practical way of increasing it. In modern machines, the field is made very strong and is divided up into many separate magnetic circuits, this having the advantage of increasing the E. M. F. and at the same time reducing armature reactions and distortion of the field, so there is very little necessity, if any, of changing the position of the brushes on changes of load.

CHAPTER X.

GENERATORS.

A consideration of the elementary theory of the generator shows that in order to produce a continuous current in the external circuit, there must be (1) **a magnetic field,** (2) a collection of conductors called the **armature,** designed to revolve in the magnetic field, (3) an arrangement of conductors called the **commutator** for commuting the reversals of the current in the armature into one direction in the external circuit, and (4) an arrangement of conductors, called **brushes,** for making connection between the revolving armature and the external circuit.

The magnetic field may be produced by permanent magnets or by electromagnets, and in the latter case the current may be taken from some external source or from the current produced by the revolving armature itself. If the current is taken from the armature, all of the current may be used to produce the magnetic field, in which case the generator is called a **series** generator; or only a part of the current may be used, the generator then being called a **shunt** generator; or, again, a combination of these two methods may be used to energize the field magnets, in which case the generator is called a **compound** generator.

Separately Excited Generator.

In this form of generator, the magnetic field is produced by a current from a separate source of supply while the current due to the induction in the armature is lead off from the brushes to its external circuit. A typical form of separately excited generator is shown in Fig. 72.

Series Generator.

In this form of generator, the magnetic field is produced partly by the permanent residual magnetism of the poles, due to the metal

of which they are made, and to the current that is produced as a result of the induction in the conductors on the armature. The armature conductors are connected in series with the external circuit by means of the brushes and the whole current is lead around the field pieces. When this current flows around the metal field pieces, they become strongly magnetic, producing a strong magnetic field in the region in which the armature is made to revolve. The stronger the current the greater is the magnetic field, or at least up to the point of saturation of the field magnets. By this is meant

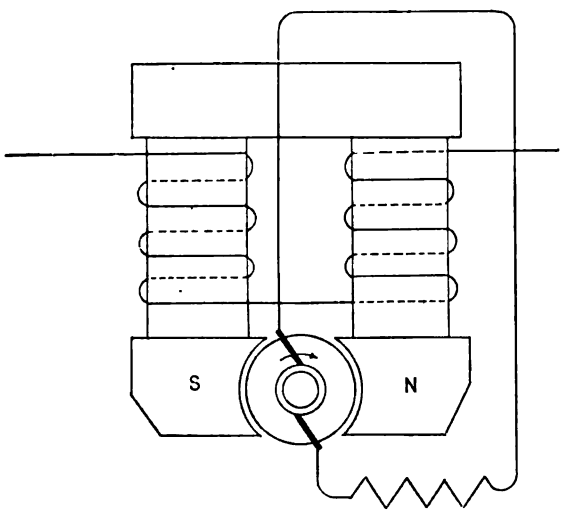


FIG. 72.—Separately Excited Generator.

the limit in the number of lines of force which the magnetic material is capable of producing. The number of times the series winding is carried around the field magnet spools, multiplied by the number of amperes flowing, is called the *ampere turns,* and the saturation of the magnetic material depends upon a given number of ampere turns, beyond which the magnetization will not increase, but will rather decrease.

Fig. 73 shows the typical form of series generator, showing the brushes, the field winding, the external circuit, and armature conductors all connected in series with one another.

In this form of generator, it is seen that no E. M. F. is generated in the armature as long as the external circuit is open, for then there is no current flowing around the field magnets. There may be a small E. M. F. generated due to the residual magnetism, but of course is not manifested as the circuit is not complete. In order then that this form of generator shall *build up,* that is produce a difference of potential at the brushes, the *external circuit*

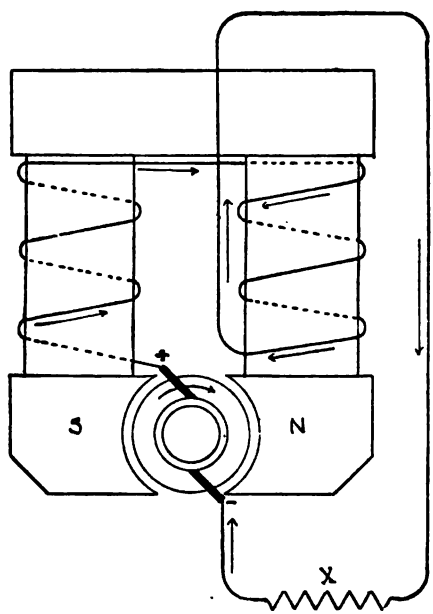


FIG. 73.—Series Generator.

must be completed, and the resistance must not be too high, or the small difference of potential, due to the residual magnetism, may not be sufficient to force current through it, and thus prevent any from flowing around the field magnets. Then, again, a series generator will not generate until a certain speed is reached. Any increase in the external resistance lessens its power to supply current, lessening as it does its ampere turns and consequently its effective magnetism. Any decrease in the external resistance, as

in adding lamps in parallel, has the effect of increasing the current, increasing the magnetization, and thus again the current, and a continued decrease in resistance might result in burning out the armature or the lamps. The series coils must carry the whole current so they must be of large wire to prevent overheating, and of only a few turns, for as the proper magnetization is proportional to the ampere turns, the latter may be obtained by a large current, as in this generator, and a small number of turns.

Regulation.—The E. M. F. of a series generator may be regulated at a given speed (1) *by controlling the current in the external circuit,* (2) *by cutting out part of the magnetizing coils,* and (3)

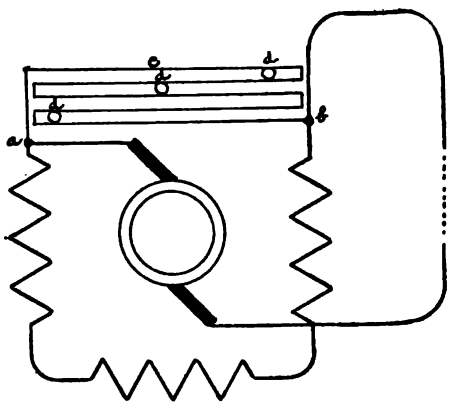


FIG. 74.—Series Shunt.

by sending part of the main current through a shunt to the series windings. The only one of these three that finds a practical use in the series windings as applied to a compound generator is the last and this should be understood, as it is the method used in the final compounding of compound generators.

In Fig. 74, *a* and *b* are the terminals for the series windings, and in addition to the series winding, these terminals are connected by a shunt circuit in which there is a variable resistance *c,* regulated by the short-circuiting plugs *d.* Part of the main current that would otherwise go around the series coils is shunted through this circuit, and by moving *d* the magnetizing current and consequently the E. M. F. at the brushes may be regulated.

Characteristic Curve.—The characteristic curve of a generator is a name given to a curve that may be plotted to show the relation between the number of volts generated in a generator and the resulting number of amperes, using volts as ordinates and amperes as abscissæ. The volts used may be the total volts and the amperes the total amperes, in which case the curve is called the *total* characteristic curve. In the case of the series generator, if the curve is plotted with the E. M. F. at the terminals and the external current, also in this case, the internal current, the curve is called the *external* characteristic curve. The *internal* characteristic of a series generator would be a straight line, the tangent of the angle this line makes with the current line being equal to the internal resistance.

The curve used in compounding generators is the external characteristic curve, but as they all show the interior workings of the generator under varying conditions a typical curve of each is shown with a mention of some of the facts that can be learned from them.

In Fig. 75 the line *OE* represents the total characteristic curve of a series generator for a given speed, the ordinates being volts and the abscissæ amperes, being plotted from the total E. M. F. generated and the resulting external current. This curve starts a little distance above the zero line, showing a certain amount of residual magnetism. The curve ascends first at a steep angle, then curves around and again assumes nearly a straight course. In this generator the magnetization increases with the current, and so the E. M. F. increases rapidly at first, giving the straight portion of the curve. As the current increases, the magnets approach saturation, so any increase in current does not produce a corresponding increase in E. M. F. and this is shown by the curving or flattening for a short space in the curve. If a still further increase takes place, armature reactions, demagnetizing, and cross magnetizing effects take place, and a shifting of the brushes due to the increased current causes a marked demagnetizing effect and in some generators causing a decided drop in the curve. This curve shows at what point saturation commences to be manifested, when it has really reached the saturation point, and the current necessary to produce the maximum E. M. F., or rather the current produced by the maximum E. M. F. and at what time the most serious of the arma-

ture reactions take place. It also shows at what current, or the limits of current, the total E. M. F. is most nearly constant.

The curve *Oe* is plotted for the total current and the difference of potential at the brushes or terminals. The difference in the ordinates of the total and external characteristics show the volts that are lost in overcoming the internal resistance, that of the armature and series windings, and from being useless as far as

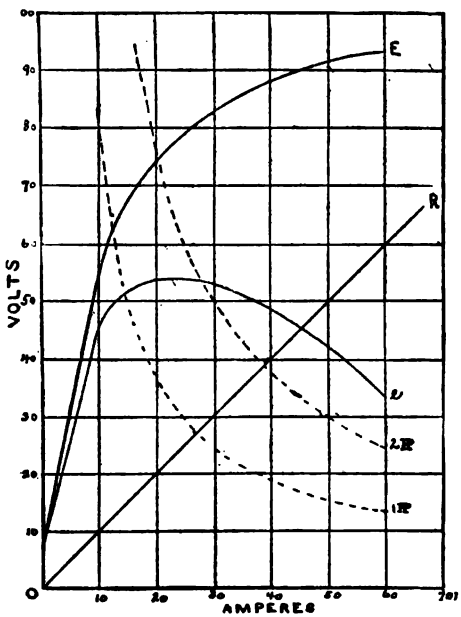


FIG. 75.—Characteristic Curves of Series Generator.

external electrical energy is concerned are called "*lost volts.*" This curve shows between what limits of the external current the difference of potential at the terminals is most nearly constant, consequently at what load the machine could be used with the least variation in E. M. F.

The full straight line *OR* is the curve of internal characteristic, and its ordinate at any point represents the "lost volts" for the corresponding current, and is equal to that current multiplied by

the sum of the armature and series winding resistances. This curve then represents the difference between the other two, and having either two, the remaining one may be plotted. As the internal resistance is known, the internal characteristic may be easily plotted, and the data for the external characteristic may be obtained by properly connecting an armature in circuit and attaching a voltmeter to the terminals. Then by adding to the ordinates of the external characteristic the ordinates of the internal for the same current, the total curve can be plotted.

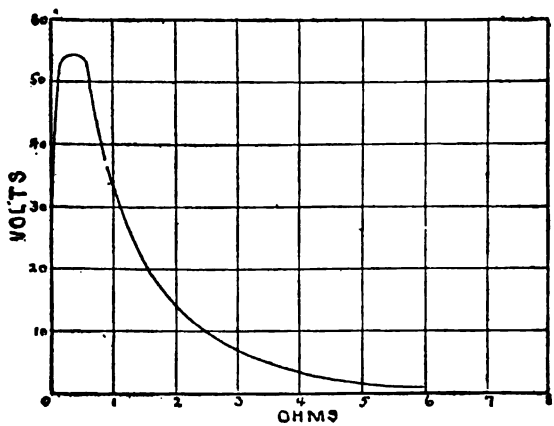


FIG. 76.—Curve Showing External Resistance and Terminal Voltage, Series Generator.

Horse-Power Lines.

Another interesting fact in connection with these curves is that they can be made to show the horse-power which is being developed at any particular part of the circuit. These horse-power lines constitute a system of rectangular hyperbolæ, the axes of volts and amperes being the respective asymptotes. That is $xy = a$ constant, x being volts and y amperes. The one horse-power line should be the locus of all the points such that the product of the ordinate and abscissæ of every point is equal to 746 watts. Thus one point would be 74.6 volts and 10 amperes, another 37.3 volts and 20 amperes, and so on. The two horse-power line should be a result

such that the product of ordinate and abscissæ at every point should be 2 × 746 watts.

An examination of the resistance curve or line shows that, if the resistance is above a certain value, the angle it makes with the ampere line being greater than the angle made by the slope of the total characteristic curve, the machine cannot build up; and it also shows that while running, if from any cause the resistance is suddenly increased, the machine will rapidly unbuild or lose its magnetism, that is, the ordinate of the resistance becomes negative as applied to the external curve. These curves explain a great many things in connection with the running of generators that were known before simply as facts.

Another interesting curve useful in compounding generators is a curve showing the relation between the external resistance and the difference of potential at the terminals. A typical curve is shown in Fig. 76, but its application will be deferred until compound generators are considered.

Shunt Generators.

In this generator, the magnetic field is produced partly by the permanent residual magnetism of the field pieces and by a shunt current that is led off from the terminals of the machine. As the current in the shunt field, as it is called, is lost as far as any external electrical energy is concerned, it is sometimes called the "*lost amperes.*" As this loss should be as little as possible, in well-designed machines not more than 5 per cent of the armature current passing through the fields, the resistance must be high, and in order to produce the proper number of ampere turns, the number of turns must be very great, so the shunt winding usually consists of a very great number of turns of fine wire.

Fig. 77 shows the typical form of shunt generator, the shunt current being taken off from the brushes around the pole pieces, the main current being taken off from the brushes through the external resistance *R*.

This machine will not build up if the external circuit is closed, for then all the current generated would tend to take that path on account of its resistance being so much smaller than that of

the shunt windings. If the external circuit is open, and the armature made to revolve, owing to the small amount of residual magnetism in the pole pieces, there will be generated a small difference of potential at the brushes, and this difference of potential will cause a small current in the shunt windings, which will in turn, increase the magnetization, this increasing the E. M. F. at the brushes, and so the machine gradually builds up to full voltage,

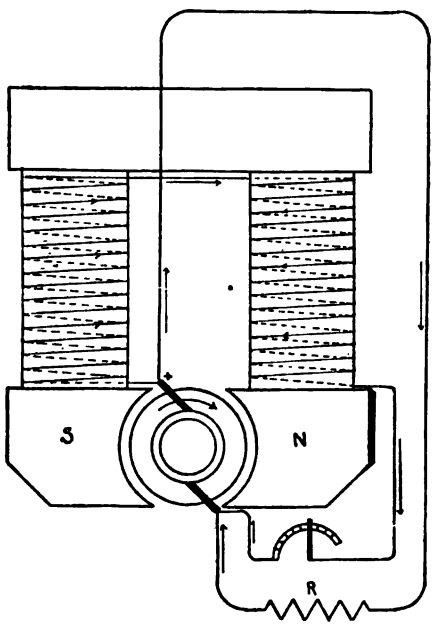


FIG. 77.—Shunt Generator.

attaining its full value when no current is flowing in the external circuit, and all the armature current is in series with the shunt current. When an external current flows due to closing the external circuit, the difference of potential at the brushes gradually falls, on account of the internal resistance of the armature conductors and of the reactions of the current on the field. A greater proportion of the whole current follows the external path, thereby lowering the E. M. F. at the brushes, and consequently reducing the

shunt current, which decreases the magnetization, and which reacts to still lower the E. M. F., so as the external resistance gradually falls, the total current may increase for the time, but a less proportion flows around the field, and the voltage falls, and if a certain low external resistance is reached, the machine will rapidly unbuild and the voltage and current fall together to zero.

Regulation.—In order to compensate for the decrease in the E. M. F. when load is thrown on a shunt generator, a rheostat of comparatively high resistance is placed in series with the shunt winding, and so adjusted that when no external current is flowing only enough current flows through the field to produce the proper E. M. F., and this is kept constant by throwing out some of the resistance as the load increases, so that the shunt circuit will have an increasing or rather a steady instead of a decreasing current, thereby maintaining a constant magnetization and constant E. M. F.

Characteristic Curves of Shunt Generators.—There are five curves that show relations existing between the volts and amperes in a shunt generator, one internal characteristic and four external curves. The internal curve, plotted with the total volts and the total current when the external circuit is open is very similar to the total characteristic curve of the series generator. When the external circuit is closed, there are four variable quantities, namely, the total E. M. F., the E. M. F. at the brushes or terminals, the armature or total current, and the external current. Calling the total E. M. F. *E*, the E. M. F. at the terminals *e*, the total current *Ca*, and the external circuit *C*, four curves can be plotted, *e* and *C*, *e* and *Ca*, *E* and *C*, *E* and *Ca*. Of these *e* and *C* is the one principally concerned in the compounding of generators, though all are of interest and are shown in Fig. 78.

Curve No. 1 is plotted from *e* and *C*, No. 2 from *e* and *Ca*, No. 3 from *E* and *C*, and No. 4 from *E* and *Ca*. *OA* is drawn at such a slope that the tangent of the angle it makes with the ampere axis represents the resistance of the armature, and *OS* at such a slope that the tangent of its angle represents the resistance of the shunt winding.

If curve 4, obtained with the total E. M. F. and the total current, is plotted, the others may all be obtained from it. Curve 2

is obtained from 4, by subtracting from the ordinates lengths which are included between *OA* and *OC*. Thus the point 2 is obtained by subtracting the distance *CF* from *C*4. The distance *CF* represents the "lost volts" for the current *OC* corresponding to the E. M. F. *C*4, and similarly the ordinates represent the lost volts for any corresponding armature current.

Curve 3 is obtained from 4 by subtracting the abscissæ lengths which are included between *OS* and *OD*. Thus the point 3 is obtained by subtracting the distance *DE* from *D*4. The distance

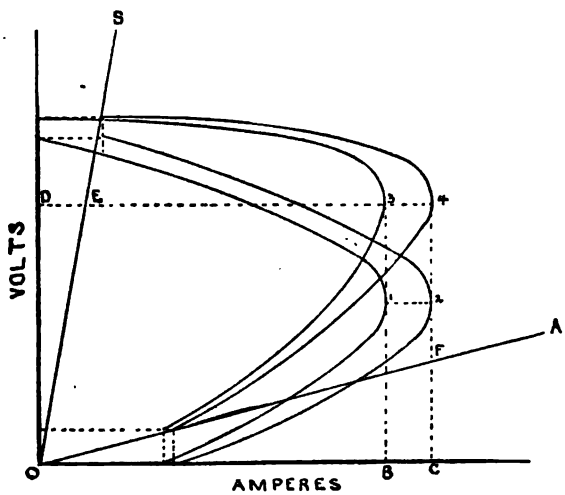


FIG. 78.—Characteristic Curves of a Shunt Generator.

DE represents the amperes in the shunt circuits, or the "*lost amperes*" for the difference of potential *C*4, and similarly the abscissæ between *OS* and *OD* represent the lost amperes for any corresponding difference of potential.

Curve 1 is obtained by taking the ordinates (lost volts) from curve 3 and the abscissæ (lost amperes) from curve 2 corresponding to any point on curve 4.

In practice, it is more usual to plot curve 1, by observing the difference of potential at the terminals with a voltmeter and measuring the external current with an ammeter. Curves 2 and 3 can then be drawn, and from these two, curve 4 can be plotted.

These four curves are curiously different from that of the series generator. The volts are a maximum when the external circuit is open, and as the external current gradually increases, the difference of potential gradually falls, due to the fact that a smaller proportion of the total current is now flowing around the field magnets. At first this fall is gradual, but at a certain current the curve rapidly turns and then descends rapidly towards the origin in a nearly straight line. This shows why a shunt generator will not build up if the external circuit is closed, and how it rapidly unbuilds if the external resistance is lowered to a certain amount. The straight

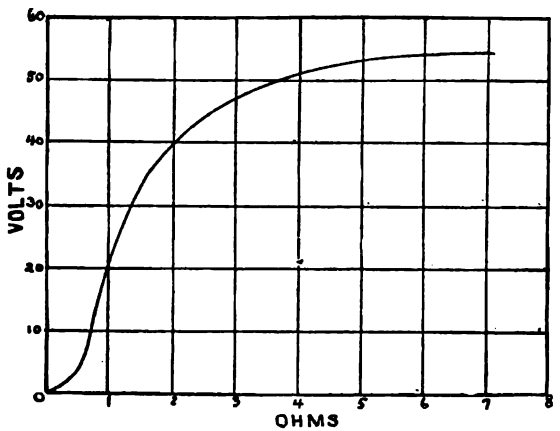


FIG. 79.—Curve Showing External Resistance and Terminal Voltage, Shunt Generator.

portion shows the critical state, and shows that if the external resistance is altered the slightest degree, both the volts and amperes alter to a very great degree.

These curves show that the shunt generator will only work if the resistance of the external circuit is greater than a certain value, while the series generator will only work if the resistance is less than a certain value.

A curve (Fig. 79) showing the relation between the volts and resistance is instructive, as by its combination with the corresponding curve of the series generator the curve for the compound generator is made.

Compound Generators.

Having now seen the principles upon which the series and shunt generators are built, we are in a position to take up the compound generator, which is simply a combination designed to produce a constant difference of potential at the terminals irrespective of the external current or resistance. A compound generator can then best be considered as a shunt generator, upon which there is also wound a few turns of series windings. Under the curve for the shunt generator it was seen that as the external current was increased, or what amounts to the same thing the external resistance

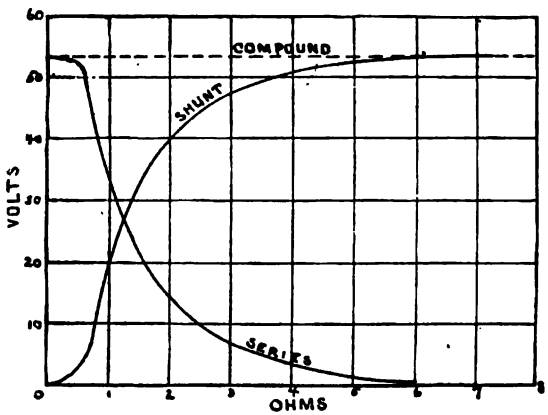


FIG. 80.—Curve of Compound Generator.

decreased, the difference of potential gradually fell and in the series curve, the difference of potential gradually increased under the same circumstances. So by combining these two curves, a curve of constant potential or a straight line might be produced, and that is the sole object of the compound generator. This could be well represented by combining the two external curves of the series and shunt generators, but is still better shown by combining the two curves plotted with volts and ohms, for each generator as shown under the respective heads of series and shunt generators. These curves are shown in the figure.

The shunt curve in Fig. 80 shows what was seen before, that the greatest E. M. F. occurs when the external resistance is greatest,

or when the external circuit is open, and as the resistance is gradually decreased, or the external current gradually increased the E. M. F. gradually fell. The opposite takes place in the series generator, for when the resistance is high scarcely any current flows around the field spools, and there is practically no E. M. F., but as the resistances decreases, or current increases, the E. M. F. gradually rises. If there is a proper relation between the resistances of the two windings, one will raise the E. M. F. just as much as the other lowers, so the sum of their ordinates at any point will be constant, and the compound characteristic is represented by the dotted straight line, marked compound.

In the type of compound generator used in the navy, in addition to the fixed shunt and series windings, there is a regulator introduced in the shunt field as explained under the shunt generator, and a shunt to the series winding as explained under the series generator. This latter is adjusted when the machine is being compounded, and when once adjusted to give the proper difference of potential should not thereafter be tampered with, but any variations in the E. M. F. should be regulated by the shunt field rheostat.

The Building Up of a Generator at Starting.

When a self-excited generator is started, there is a small E. M. F. induced in the armature coils due to the magnetic field produced by the small residual magnetism. This small E. M. F. produces a current which, flowing around the magnets, *strengthens* the field, which in turn induces higher E. M. F.; this produces greater current which still more strengthens the field and so on until the machine is built up to full voltage. This operation is called **building up**, and there can be no building up unless there is some residual magnetism. If the field magnets show no residual magnetism whatever, the field circuit should be connected with some outside source of current, either a few cells of a storage battery or the current from a running machine.

If the connections of the field are such that the induced current tends to *weaken* the residual magnetism, then the machine cannot build up at all. With a given direction of rotation of the armature and a certain polarity, the induced current tends to go in a certain

direction. If now the connections are such that the induced current due to the residual magnetism weakens it, the current will also weaken. If the current was strong enough to reverse the polarity of the field magnets, then the induced currents would flow in the opposite direction and would be again acting to weaken the field.

With a given direction of armature rotation and given field connection, a generator does build up; it cannot build up, if its direction of rotation be reversed, or if its field connection is reversed; but it will build up, however, if both the direction of rotation and field connections are reversed at the same time.

If a generator does not build up, it may do so by changing either the direction of rotation of the armature or by changing the field connections.

Comparison of Terminal Voltage in Different Generators.

The field current of a separately excited generator can be kept constant, so that the armature flux is practically constant except for the demagnetizing effect of the armature when delivering its current.

Separately Excited Generator.—As the current rises, due to a lessening of the external resistance, the drop of potential in the armature, Cr_a, increases, so the terminal voltage decreases with an increase of current, and also slightly due to the increased demagnetizing effect when the current increases.

The terminal voltage falls off as the speed decreases, as the total E. M. F. depends on the speed and flux, as seen from the fundamental equation, and the total and terminal voltages vary almost in proportion with the speed.

Series Generator.—The total E. M. F. is proportional to the speed and for any given external current, the terminal voltage varies directly with the total E. M. F. and with the speed.

The voltage is zero when the current is zero and increases rapidly with the external current, the lost volts increasing with increase of current. With a certain speed, the terminal voltage falls off as the external resistance is decreased.

Shunt Generator.—A decrease of speed in a shunt generator

causes a decrease in both the total and terminal voltages, and the lessening of the terminal voltage decreases the field current and consequently the magnetism, so the voltages fall more in proportion than in a separately excited machine.

An increase in the external current causes a greater decrease in the terminal voltage than in a separately excited generator, because on account of the increased armature current, the drop is greater, and consequently the terminal voltage is less, and also the field excitation is less.

Compound Generator.—The field excitation of a compound generator is increased by an increase in the external current due to the series windings. If the series winding has enough coils, it may counterbalance the demagnetizing action due to the increased current and the drop in the terminal voltage due to the shunt winding and may increase the total E. M. F.

If the series coils are made of just enough turns to counteract the drop in the armature and field due to the increased current, $C_a r_a + C_a r_m$, the terminal voltage may be kept approximately constant.

If the series windings has the effect of increasing the total E. M. F., that is, if it more than compensates for the drop, the terminal voltage will increase with increase of current, and the machine is said to be **over compounded.**

Over Compounding.

By proper adjustment of speed and resistances, machines can be made to give a constant difference of potential for a certain range of external current which may not be constant over the entire limit of external current. A machine is said to be over compounded when the difference of potential at the terminals is higher than the E. M. F. at some point in the circuit over which the E. M. F. is to be constant for the range of current used. It is usually due to a preponderance of the series winding over the shunt. There is no necessity of over compounding generators on board ship for the leads are short and their resistances low. It is, however, absolutely essential to know over just what range of external current the E. M. F. is constant. Thus, of two machines built entirely

alike of 100-amperes capacity, one might have an absolutely constant E. M. F. from 0 to 50 amperes, and not so constant for the rest of the load, while the other might be not quite so constant in the first half of its range, but entirely constant in its second half. In running these machines in parallel, they would only automatically work so to speak, over the range of current common to both in which the E. M. F. was constant, though of course they could be regulated so as to divide their loads equally by adjusting the shunt rheostats.

Uses of Different Classes of Generators.

Separately excited generators are used mostly for testing where a constant E. M. F. is desired or where changes of speed affect but slightly the terminal voltage.

Generators used for charging storage batteries are usually separately excited, as they are working against an opposing E. M. F. which would act back through the generator if it was not immediately disconnected on stopping. Separately excited generators are much less likely to have the field magnetism reversed. They are also used largely for electroplating.

Series generators cannot be used where constant voltage is desired, but can be used for supplying constant current at varying voltages, the voltage being regulated by devices to keep the current constant on changes of the external resistance.

Shunt or compound generators are used for delivering varying current at constant voltage, as in electric lighting and in most forms of power. They are driven at or near constant speed by the motive power available.

The fields of alternating current generators are separately excited, as a steady field could not be produced by the alternating current of the armature.

CHAPTER XI.

EFFICIENCIES AND LOSSES OF GENERATORS.

Efficiency as applied to a generating set, that is, a generator and the power that drives it, is a term used in more than one sense, and to intelligently understand what is meant, the definitions of the terms ordinarily used will be given, and reasons given for the existing differences.

Gross Efficiency.

On board ship, the generators are directly connected to the shaft of the driving engine, either by means of a solid shaft or by a clutch bearing. All of the power developed by the engine and applied to the armature is not converted into electrical energy in the generator, and the gross efficiency is a term applied to express the relation between the *gross power actually applied to the armature shaft* and the *gross electrical power converted in the armature.* One of these is mechanical power, the other electrical, and to obtain the percentage efficiency, they must both be expressed in the same units, either both electrical or both mechanical.

The total power applied to the shaft is ordinarily obtained by taking indicator cards of the engine while running at the standard speed. The total electrical power converted can best be determined by calculation; by measuring the total external current and the difference of potential at the terminals, and from these quantities, by means of the dynamo equations, find the total E. M. F. and the armature current. Their product divided by 746 will give the horse-power actually converted, and the percentage of the total horse-power that this represents will be the gross efficiency. It must be noted that in expressing the gross efficiency, it is necessary to state under what conditions of external load the generator is running, for the total power converted depends upon this quantity and hence does the efficiency.

Electrical Efficiency.

This is a term given to express the relation between quantities that are entirely electrical, and might be considered the efficiency of the generator itself. It is the relation between the *total power actually converted in the generator* and the *net output, or the electrical energy available at the terminals.* The output is measured by a voltmeter and ammeter properly connected with the generator running at its rated speed, and with the load for which the efficiency is desired. With these quantities the total E. M. F. and the total armature current are obtained as in the case under gross efficiency. The product of the total E. M. F. and armature current gives the total number of watts converted, and the product of the difference of potential at the terminals and the external current gives the number of watts available for useful work, and the relation between these two quantities expresses the electrical efficiency.

Commercial Efficiency.

This is a term given to express the relation between the *total power applied to the shaft of the generator and the total electrical energy available at the terminals,* and as has been seen, must be the product of the other two efficiencies, the gross and electrical. This is the real measure of the efficiency of the generating set, and represents the relation between the power that is put in the set, the *input,* and the power that is taken out, the *output.* If the other two efficiencies are high, of course the commercial efficiency will be high also, though lower than either one. The quantities concerned are directly measured, one by the indicator cards of the engine, the other by voltmeter and ammeter; and the resulting efficiency is the one required by the standard specifications, full load on the generator being the standard load.

Losses.

Losses in generators are of two kinds, *electrical* and *mechanical,* and on their values depend the various efficiencies. The losses which represent the difference between the total power applied to the armature shaft and the total power converted in the armature

are partly mechanical and partly electrical, being losses in friction at the bearings, friction at the brushes, between them and the commutator, air friction of the revolving armature, eddy currents in the pole pieces of the magnetic field and in the conductors on the armature, and in the armature core, and a hysteresis loss in the armature core due to the armature revolving in a magnetic field. All of these losses are manifested in the form of heat which is dissipated into the air or tends to heat the parts involved and, being brought into existence by the power supplied, represents so much waste energy.

Of these losses, the friction losses are small and can be reduced by proper mechanical means. The loss due to the eddy currents induced in the pole pieces is also small, especially in forms of armature that are not slotted. These eddy currents are induced in and circulate round the pole pieces, being due to the relative motion of the lines of force and the iron masses, the field being apparently dragged along by the revolving armature, and the magnetic circuit being broken as the tip of the pole is left. These eddy currents can be reduced to a certain extent by laminating the pole pieces, and by increasing the size of the pole tip on the leaving horn of the pole piece, and cutting it away under the entering horn; the last arrangement also reducing the demagnetizing and cross magnetizing effect. The eddy currents tend to heat the iron masses, and this heat represents so much lost energy.

Loss due to eddy currents set up in the armature conductors themselves is very small indeed and could only be appreciable, if at all, in armatures having heavy solid bars as conductors, but could have no effect in armatures where the conductors are made up of stranded small wires.

The principal loss in power that is not converted into electrical energy in the armature is that due to hysteresis which is due to the reversals of the magnetic field and its reaction on the iron masses of the armature core. *Hysteresis* is the name given to express the magnetic lagging of effects behind the causes which produce them. If the magnetism be rapidly reversed in a magnetic substance, there is a lagging of the field behind the cause of the reversal and to this phenomenon the name hysteresis has been given. The rapid

reversal of a magnetic field will produce heat in the magnetic substance, which is a loss from the power which produces the change. The revolution of the generator armature in a magnetic field has the effect of reversing the magnetic field; the same effect, in fact, as though the armature was at rest and the field was actually reversed. Laminating the iron core of the armature has the effect of reducing eddy currents and a consequent loss due to heat they produce, but it does not affect the hysteresis loss, as that depends only on *the magnetic substance of the core,* on *the flux density* of the magnetic field, and on the *number of reversals* of the field; this last depending on the speed and number of poles.

The loss due to hysteresis is reduced by using as armature discs soft annealed metal that does not show much residual magnetism, and this is effected by using a metal approaching pure iron, having little of the steel characteristics.

The loss in armatures due to eddy currents and hysteresis may be separated, as the eddy currents are true electrical currents, and their heat waste varies as the square of the current, and the hysteresis loss only as the current.

The difference between the power actually converted in the armature and the electrical output of the generator is represented by the losses which take place in the conductors of the generator itself; that is, in the armature conductors and in the conductors that make up the series and shunt windings. The losses in the windings of the field are designated **field losses,** and those in the armature, **armature losses,** to distinguish them from the losses in the armature core, which are sometimes called **core losses.**

In a compound generator there are two field losses, that due to the series windings and that due to the shunt windings. When the generator is giving out its rated E. M. F., the shunt loss is constant as the current is constant to produce the constant magnetization, and the resistance being unchanged. The loss then expressed in joules would be $C^2_s r_s t$. It must be borne in mind, however, that if there is a regulator in series with the shunt field, loss due to its resistance must be added to the other, in joules being $C^2_s rt$ (regulator). The loss in the series windings depends on the external load, the series current varying with the armature current

at any time, its loss in joules being $C^2_m r_m t$. The armature loss depends on the external load, and at any time would be $C^2_a r_a t$ joules. All these expressions show that the smaller the resistances, the smaller the losses—and the ideal generator would be one of infinitely small resistance. These are all heat losses, the effect of which is to heat the conductors through which the currents flow, and unless some means is taken to allow the heat formed to be radiated off, this heat forms a serious drawback, independent of the loss of electrical energy. The series coils are usually in the form of ribbon, for the double purpose of allowing greater radiating surface and for the ease with which they can be wound on the magnet spools.

These losses can be considered in another sense, that of the power used to force the currents through the several resistances. For instance, in the case of a long-shunt compound-wound generator, the difference of potential at the terminals being e, the power in watts expended in forcing the current through the shunt winding would be eC_s. That lost in forcing the current through the series windings would be $(e' - e)C_m$, and that lost in the armature $(E - e')C$.

From the dynamo equations, Chapter XII,

$$e = C_s r_s,$$

or

$$eC_s = C^2_s r_s$$

$$e' - e = C_a r_m$$

$$(e' - e)C_m = C^2_m r_m.$$

In the long shunt

$$C_a = C_m$$

and

$$(E - e') = C_a r_a$$

$$(E - e')C_a = C^2_a r_a.$$

Multiplying these by t, expresses the watts lost as joules.

The total power converted in the armature is the product of the total E. M. F. and the total armature current or EC_a; the total available power is the product of the difference of potential at the terminals and the total external current or eC. The difference of these two must represent the total copper losses, or in the long shunt compound generator,

$$EC_a - eC = C^2_s r_s + C^2_a r_m + C^2_a r_a.$$

The total available power in the external circuit is C^2R, or

$$EC_a = C^2R + C^2_s r_s + C^2_a r_m + C^2_a r_a .$$

$$\therefore \quad eC = C^2R,$$

which is of course true as

$$e = CR.$$

The expression for the electrical efficiency would be

$$\text{Efficiency} = \frac{eC}{EC_a};$$

or, as given under dynamo equations,

$$\text{Efficiency} = \frac{C^2R}{C^2R + C^2_s r_s + C^2_a r_m + C^2_a r_a}.$$

Limit of Output.

In the case of a generator designed to give a constant difference of potential at the terminals, the amount of current flowing through the armature depends on the external resistance. As this resistance is reduced by adding incandescent lamps in parallel, it becomes a matter of importance to know how far this resistance may be lowered; or, in other words, how much current can be safely taken from the generator. In a given generator the calculations are based on a given maximum current, and the conductors of the armature are calculated to safely withstand this current; but the question is, what limits the current and what should be the basis of the calculation? We have seen under *losses* that the internal losses in the generator are all in the nature of heat losses, the number of joules lost in a given time being C^2rt, for the part of the circuit under consideration.

Heat.—The heat formed by the currents tends to dissipate itself into the surrounding air, but if the heat is produced by the current faster than it is radiated, it is very evident that the parts themselves will be heated. If the generator is at rest and has been for some time, all of its parts will attain the temperature of the air; if now the generator is started with an external current, heat is formed in the conductors, and if it is radiated as fast as produced there will be no rise in temperature. This is seldom the case, however, and the

temperature of the parts will go on slowly rising. The greater the current taken from the generator, the greater will be the increase in temperature for the same time. Now it is very evident that one limit of the amount of current is the temperature limit due to that current. At a certain temperature the materials used in the insulation of the conductors and the different windings of the generator, such as paper, cotton, silk, etc., will char and disintegrate to such an extent as to be worthless for what they were designed. For a short time they may stand a temperature somewhat higher than the charring temperature, but if submitted for any length of time to a temperature of 180° F., they will quickly break down. Consequently, no current should ever be taken from a generator such that the heat formed should raise its temperature to 180° F.

If the temperature of the air is as high as 180° F., it is very evident that the machine should not be run at all, for all parts will be at that temperature, and there could be no allowable rise in temperature, due to the generator currents, so in stating the allowable rise, it is very necessary that it should be a rise in temperature above that of the surrounding air. If the machine could be kept in a room at the freezing point, and the heat imparted to the air so carried away that it would remain at the freezing point, the allowable rise due to the current would be 180° — 32°, and from this generator under those conditions, a greater current could be safely carried than at any initial higher temperature.

The specifications for generators used in the service state that after a four-hours' full-load trial, no part of the machine shall be allowed to be higher than 40° C., greater than the temperature of the room; or, in other words, the temperature due to the armature current shall not be greater than 40° C., above the temperature of the air. The average temperature of the air is to be taken as 25° C.

Sparking.—Besides the limit of temperature which limits the amount of current that can be safely carried, there is another consideration that will be lightly touched on. As the current from the armature increases, the magnetic field of the armature core increases and the magnetic field of the field pieces remaining constant, certain reactions take place between these two fields. These reactions

have a tendency both to cross magnetize and to demagnetize, one effect of which is to necessitate the shifting ahead of the brushes from their normal positions. The brushes should ordinarily be placed in the neutral part of the field, that is, where the induction in the armature coils is a minimum, and in this position there will be little or no sparking. If the current is increased, greater reactions take place, necessitating further movement of the brushes to reduce sparking, but this movement of the brushes produces further change in the magnetic reactions, and if the current is strong enough the armature field may be powerful enough to overcome the field, and there can be no position found in which the brushes will have no sparking. This sparking of course is very injurious, and when heavy, rapidly wears away the brushes and the commutator segments, rapidly pitting and scarring them, and the heat due to the sparking may be great enough to fuse two or more adjacent segments, thereby short-circuiting their coils, and soon burning them out. This sparking can be reduced by good preliminary design; by making the field magnets relatively very powerful in relation to the armature field, but still in any given generator, a current in excess of the designed amount may produce injurious sparking, so this may well limit the amount of current that may safely be taken from any machine.

CHAPTER XII.

DYNAMO EQUATIONS.

In order to know just what is taking place in a generator when it is running at any certain speed with a given load in the external circuit, the dynamo tender should have a knowledge of the simple equations connecting the electromotive forces, currents, and resistances of the various parts of the field windings, armature, and external circuit. These follow directly from a consideration of Ohm's law and the laws of divided circuits previously given. These equations will enable one to calculate just what any particular generator is capable of doing, and are needed in order that the several efficiencies may be calculated under any given conditions. Of course they are used when the generator is under design, but with which this is not concerned. Examples will later be given to show their application.

The following notation will be used consistently throughout both with generators now and motors later:

E = total E. M. F. generated by generator or motor,
e = difference of potential at the terminals,
e' = difference of potential at the brushes,
$\mathfrak{E}$ = difference of potential at the motor terminals,
C_a = armature current,
C_s = shunt current,
C_m = series current,
C = external current,
r_a = armature resistance,
r_s = shunt resistance,
r_m = series resistance,
R = external resistance.

Series Generator.

In the series generator, there is but one circuit (Fig. 81), so $C = C_a = C_m$.

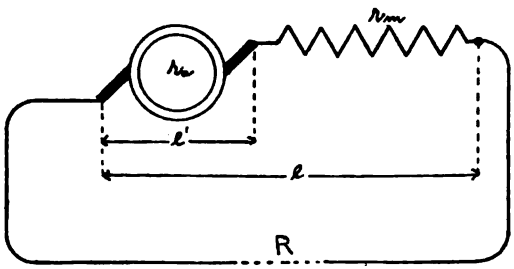


FIG. 81.—Series Connections.

By Ohm's law:

The fall of potential around the whole circuit $E = C(R + r_a + r_m)$,
" " " from terminal to terminal $e = CR$,
" " " " brush to brush $e' = C(R + r_m)$,
" " " through series windings $e' - e = Cr_m$,
" " " " armature $E - e' = Cr_a$.
Useful work in external circuit $= Cet = C^2Rt$ joules.
Total work in circuit $= CE = C^2(R + r_a + r_m)t$ joules.
Electrical efficiency $= \frac{\text{Useful work}}{\text{Total work}} = \frac{C^2Rt}{C^2(R+r_a+r_m)t} = \frac{e}{E}$.

The expression for efficiency shows that it is a maximum when both r_a and r_m are very small.

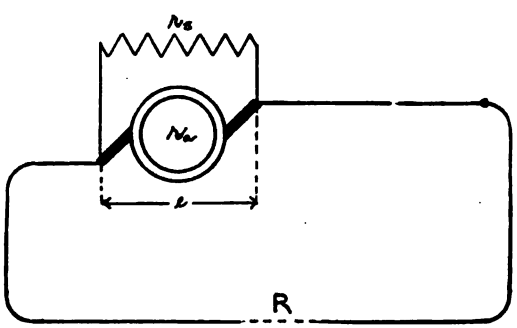


FIG. 82.—Shunt Connections.

Shunt Generator.

In the shunt generator (Fig. 82) there are three currents, one through the shunt windings, one through the external circuit, and one through the armature, the latter being equal to the sum of the other two. In this case the terminals and brushes coincide.

Total resistance outside of armature $= \frac{Rr_s}{R + r_s}$.

The fall of potential around the whole circuit $E = C_a \left(r_a + \frac{Rr_s}{R + r_s} \right)$,

" " " from terminal to terminal $e = CR$,

" " " from terminal to terminal $e = C_s r_s$,

" " " through armature $E - e = C_a r_a$,

or $E = e + (C + C_s)\, r_a$

$$C = \frac{e}{R} \qquad C_s = \frac{e}{r_s},$$

or

$$E = e + \left(\frac{e}{R} + \frac{e}{r_s} \right) r_a = e \left(\frac{Rr_s + Rr_a + r_a r_s}{Rr_s} \right),$$

or

$$E = er_a \left(\frac{1}{R} + \frac{1}{r_a} + \frac{1}{r_s} \right),$$

an expression which allows E to be computed, by the several resistances being known and e measured at the brushes by a voltmeter.

Useful work in external circuit $= C^2Rt$ joules,

Work spent in shunt field $= C_s^2 r_s t$ "

Work spent in armature $= C_a^2 r_a t$ "

or

$$\text{Electrical efficiency} = \frac{C^2R}{C^2R + C_s^2 r_s + C_a^2 r_a}.$$

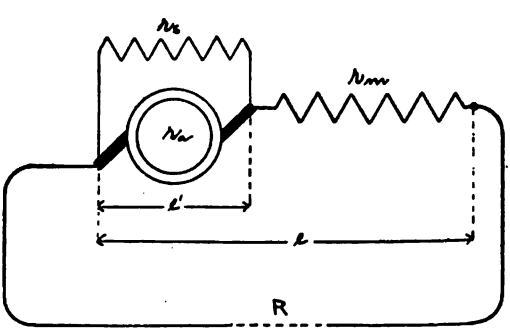


FIG. 83.—Short Shunt Compound Connections.

Compound Generator.

There are two cases in the compound generator, depending on whether the shunt current shunts only the brushes as shown in Fig. 83, or shunts both the armature and series windings as shown in Fig. 84. The former is called a **short shunt** compound generator and the latter a **long shunt** compound wound.

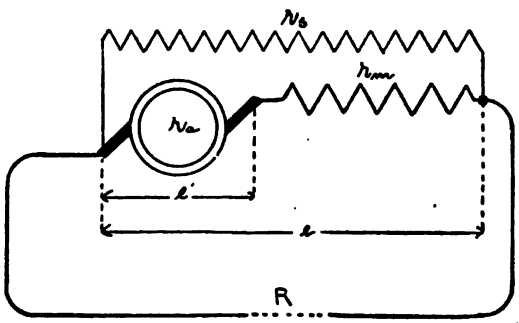


FIG. 84.—Long Shunt Compound Connections.

Short Shunt.

The fall of potential around the whole circuit $E = C_a\left(r_a + \frac{(R + r_m)\, r_s}{R + r_m + r_s}\right)$,

" " " from brush to brush $e' = C_s r_s$,

" " " from brush to brush $e' = Cr_m + CR$,

" " " " terminal to terminal $e = CR$,

" " " through armature $E - e' = C_a r_a$,

" " " through series windings $e' - e = Cr_m$.

Lost volts $E - e = C_a r_a + Cr_m$.

From the above expressions follows an equation by which the total E. M. F. may be calculated, knowing by measurement the difference of potential at the terminals and the value of the several resistances.

$$E = \frac{e(r_m r_s + R r_s + r_a r_s + r_a r_m + R r_a)}{R r_s}.$$

Useful work in external circuit $= C^2 R t$ joules,

Work spent in shunt field $= C^2_s r_s t$ "

" " " series " $= C^2 r_m t$ "

" " " armature $= C^2_a r_a t$ "

or

Electrical efficiency $= \frac{C^2 R}{C^2 R + C^2_s r_s + C^2 r_m + C^2_a r_a}$.

Long Shunt.

The fall of potential around the whole circuit $E = C_a\left[r_a + r_m + \left(\frac{Rr_s}{R+r_s}\right)\right]$,

" " " from brush to brush $e' = C_a r_m + CR$,

" " " from terminal to terminal $e = CR$,

" " " from terminal to terminal $e = C_s r_s$,

" " " through armature $E - e' = C_a r_a$,

" " " " series windings $e' - e = C_a r_m$.

Lost volts $E - e = C_a r_a + C_a r_m$.

A similar expression, as in the case of the short shunt compound, may be deduced,

$$E = \frac{e(r_m r_s + Rr_s + r_a r_s + Rr_m + Rr_a)}{Rr_s},$$

the only difference being in the next to the last term.

Useful work in external circuit $= C^2Rt$ joules,

Work spent in shunt field $= C^2_s r_s t$ "

" " series " $= C^2_a r_m t$ "

" " armature $= C^2_a r_a t$ "

or

$$\text{Electrical efficiency} = \frac{C^2R}{C^2R + C^2_s r_s + C^2_a r_m + C^2_a r_a}.$$

Problems on Generators.

1. If a shunt wound generator has an E. M. F. of 108 volts at the terminals, resistance of armature .05 ohm, field coil 18 ohms, and outside mains .2 ohm, how many incandescent lamps can be lighted if each takes .75 ampere and has a hot resistance of 130 ohms? Find the total electrical energy and the energy in the lamp circuit in watts. If the net efficiency is 82 per cent, how many H. P. must be applied to the armature?

$x =$ No. of lamps $\quad C = \frac{e}{R} = \frac{108}{.2 + \frac{130}{x}} \quad C = .75x,$

or $\quad .75x = \frac{108 \times 10x}{2x + 1300}$ or $x = 70$

$E = e + C_a r_a \qquad C_a = C + C_s \qquad C_s = \frac{e}{r_s} = \frac{108}{18} = 6$

$C_a = .75 \times 70 + 6 = 58.5.$

$\therefore \quad E = 108 + 58.5 \times .05 = 110.93$ volts.

Total electrical energy $= EC_a = 110.93 \times 58.5 = 6489.5$ watts.

Total electrical energy in lamp circuit

$= eC = 108 \times 52.5 = 5670.0$ watts

$$\text{Net eff.} = \frac{eC}{\text{H.P.} \times 746} = \frac{82}{100} \text{ or H.P.} = \frac{5670 \times 100}{82 \times 746} = 9.26.$$

2. In a shunt generator, the resistance of the armature is .02 ohm; of the shunt field 20 ohms; of the lamps and mains .4 ohm; voltage at terminals 80. Find the total current, lost volts, percentage of loss in the armature and in the field magnets, and the current through the shunt field.

$$e = C_s r_s \quad \text{or } C_s = \frac{80}{20} = 4 \text{ amperes,}$$

$$e = CR \quad \text{or } C = \frac{80}{.4} = 200$$

$$C_a = C + C_s = 200 + 4 = 204 \text{ amperes.}$$

$$\text{Lost volts} = C_a r_a = 204 \times .02 = 4.08 \text{ volts,}$$

$$E = e + \text{lost volts} = 84.08 \text{ volts.}$$

$$\% \text{ loss in armature} = \frac{4.08}{84.08} = 4.8\%.$$

$$\text{Watts lost in field} = eC_s = 80 \times 4 = 320 \text{ watts.}$$

$$\text{Total watts} = EC_a = 84.08 \times 204.$$

$$\% \text{ loss in field} = \frac{320}{84.08 \times 204} = 1.8\%.$$

3. In a given generator, the loss in the armature is 1000 watts, in the field magnets 600 watts, hysteresis and other losses 280 watts, loss in engine 5920 watts. If 57,800 watts are supplied to the engine, how many 16 c. p. lamps at 4 watts per c. p. can be lighted? What is the commercial efficiency of the plant?

Ans. No. of lamps 781.
Commercial efficiency 86.5 per cent.

4. A shunt generator, total E. M. F. 100 volts, resistance of field 16 ohms, of armature .12 ohm, of external mains .2 ohm. How many lamps taking .8 ampere and having a hot resistance of 100 ohms will this generator maintain?

If 9½ H. P. is applied to armature shaft, what is the gross and net efficiency, and energy in watts lost in field and in armature?

$x = \text{No. lamps} \qquad e = E - C_a r_a = C_s r_s = CR,$

$$R = .2 + \frac{100}{x} \qquad CR = E - (C + C_s) r_a = E - \left(C + \frac{CR}{r_s}\right) r_a,$$

or $$CRr_s + Cr_a r_s + CRr_a = Er_s \qquad C = \frac{8}{10} x$$

$$Rr_s = \frac{16 \times (500 + x)}{5x} = \frac{8000 + 16x}{5x}$$

$$r_a r_s = .12 \times 16 = \frac{192}{100}$$

$$Rr_a = \frac{12}{100} \times \frac{500 + x}{5x} = \frac{6000 + 12x}{500x}.$$

or $$\frac{8}{10} x \left(\frac{8000 + 16x}{5x} + \frac{192}{100} + \frac{6000 + 12x}{500x}\right) = 100 \times 16$$

$$x = 75 +,$$

$$C = \frac{8}{10}x = 60 \qquad R = \frac{75 + 500}{375} = 1.532,$$

$$e = CR = 60 \times 1.532 = 91.92 = C_s r_s. \qquad \therefore\ C_s = 5.745$$

$$C_a = C + C = 65.745.$$

Total energy $= EC_a = 100 \times 65.745 = 6574.5$ watts $= 8.813$ H.P.
Useful energy $= eC = 91.92 \times 60 = 5515.2$ watts $= 7.342$ H.P.

$$\text{Gross eff.} = \frac{8.813}{9.5} = 92.77\% \qquad \text{Net eff.} = \frac{7.342}{9.5} = 77.81\%.$$

Energy lost in armature $= C_a^2 r_a = \overline{65.745^2} \times .12 = 518.7$ watts,
Energy lost in field $= C_s^2 r_s = \overline{5.745^2} \times 16 = 528.08$,
Energy in lamp circuit $= C^2 R = \overline{60^2} \times 1.532 = 5515.20$
or total energy $\overline{6561.98}$ watts.

5. A long shunt compound wound generator, working with 3.6 ohms in the regulator, is furnishing a current in the external circuit of 117 amperes with a difference of potential at the terminals of 108 volts. The resistance of the shunt is 32.4 ohms, of the series field .015 ohm, and of the armature .045 ohm. Calculate the lost volts, current in armature, current in the field coils and the efficiencies, the power applied at the shaft being 20 H. P.

$$e = C_s r_s \quad \text{or} \quad C_s = \frac{108}{32.4 + 3.6} = 3 \text{ amperes},$$

$$C_a = C + C_s = 117 + 3 = 120 \text{ amperes},$$

Lost volts $= C_a(r_a + r_m) = 120(.045 + .015) = 7.2$ volts.
Total watts developed $= EC_a = (108 + 7.2) \times 120 = 13824$
" " utilized $= eC = 108 \times 117 = 12636$
" " supplied $= 20 \times 746 = 14920$

$$\text{Gross eff.} = \frac{13824}{14920} = 92.65\%.* \qquad \text{Elec. eff.} = \frac{12636}{13824} = 91.4\%.$$

$$\text{Net eff.} = \frac{12636}{14920} = 84.69\%.$$

6. A compound wound long shunt generator, resistance of armature .023 ohm, of series field .012 ohm and of shunt 20 ohms, maintains 300 110 volt 20 c. p. lamps, each lamp requiring 4 watts per c. p. Find the total E. M. F. of the machine. Allowing 15 per cent for friction and other losses, find the H. P. of the engine required to run the generator.

Watts in external circuit $= 300 \times 20 \times 4 = 24000$

$\frac{24000}{110} = 218.18$ amperes in external circuit.

$$C_s r_s = 110 \qquad C_s = \frac{110}{20} = 5.5,$$

$$C_a = C + C_s = 218.18 + 5.5 = 223.68,$$

$$E = e + C_a(r_a + r_m) = 110 + 223.68 \times (.023 + .012) = 117.8 \text{ volts}.$$

$$\text{H.P. required} = \frac{EC_a}{746 \times .85} = \frac{117.8 \times 223.68}{746 \times .85} = 41.55.$$

7. A compound wound generator, long shunt, maintains a difference of potential between the mains of the external circuit of 80 volts. 260 incandescent lamps of 16 c. p. each are placed in multiple arc between the mains, each lamp requiring 4 watts per c. p. The resistance of the armature is .02 ohm, series coils .005 ohm, and shunt current is 7 amperes. Find the gross, net, and electrical efficiencies when 26 H. P. is applied to the shaft of the generator.

Ans. Gross eff. = 94.61 %.
Elec. eff. = 90.65 %.
Net eff. = 85.77 %.

8. A long shunt compound wound generator maintains a difference of potential of 80 volts between the mains of the external circuit. 250 incandescent 16 c. p. are placed in parallel on the mains and each lamp consumes 4 watts per c. p. Resistance of armature = .0177 ohm, of series coil = .005 ohm. Shunt current = 7 amperes. Find the gross, net, and electrical efficiencies when 25 H. P. is applied to dynamo shaft.

Ans. Gross eff. = 94 %.
Elec. eff. = 91 %.
Net eff. = 86 %.

9. The machine in the preceding example develops a total E. M. F. of 83 volts; find the number of 16 c. p. lamps, resistance 100 ohms, placed in parallel that it will maintain, allowing 4 watts per c. p. Resistance of shunt = 5.8 ohms.

Ans. 148 lamps.

10. A current of 10 amperes is sent through a series of 10 arc lamps, each of 3.8 ohms resistance, by a generator whose armature is making 1000 revs. a minute. The arc lamps are then replaced by 8 incandescent lamps, each of 120 ohms resistance and arranged in 4 series of 2 each; the armature is then made to turn at 1044 revs. per minute. The resistance of the generator is 3 ohms. Assuming that the E. M. F. developed is proportional to the speed; find the strength of current in each lamp. *Ans.* 1.7 amperes.

11. A given shunt generator gives a total E. M. F. of 100 volts when run at a speed of 1000 revs. per minute. The shunt resistance is 50 ohms. What total E. M. F. will this generator induce if run at a speed of 1500 revs. per minute, if the shunt field is kept constant? What will have to be the resistance of the shunt to keep the field constant? Neglect the resistance of the armature. *Ans.* E. M. F. 150 volts.
Resist. 75 ohms.

12. The total E. M. F. of a shunt generator decreases from 125 volts to 100 volts when the speed is reduced from 1200 to 1000 revs. per minute. The armature flux at the higher speed is 10,000,000 lines. (1) What is the armature flux at the lower speed? (2) What would be the

E. M. F. of the generator at the lower speed if the armature flux were kept constant at 10,000,000 lines? *Ans.* 9,760,000 lines.

E. M. F. = 104.2 volts.

13. A shunt generator gives a full load current of 100 amperes at a terminal voltage of 125 volts, and an excitation of 20,000 ampere turns is required. To give the same voltage at zero load, 15,000 ampere turns are required. Find the number of turns required in a series field to give constant voltage. *Ans.* 50 turns.

14. A series generator has a combined armature and field resistance of .1 ohm. It gives a terminal voltage of 98 volts with a current of 20 amperes when driven at a speed of 1200 revs. per min. Find the terminal voltage when driven at a speed of 1500 revs. per minute it delivers a current of 30 amperes, if this current increases the field flux by 50%. *Ans.* 123 volts.

15. A short shunt compound wound generator delivers 50 amperes of current at 110 volts at the terminals. Calculate the commercial efficiency. Resistance of shunt field 55 ohms, of series field .02 ohm, of armature .14 ohm. All losses except copper losses equal 700 watts. *Ans.* 81%.

CHAPTER XIII.

RUNNING GENERATORS IN PARALLEL.

It is sometimes necessary to couple two or more generators together so that they may supply to a circuit a larger quantity of electric energy than either could do singly. To increase the current it is usual to connect generators in parallel exactly in the same manner that electric cells are connected in parallel; that is, by connecting the positive terminals together to a common conductor and by connecting the negative terminals together or to a common conductor.

Suppose a ship's plant was composed of three units of 800 amperes each. As long as the current to be carried is below the capacity of one machine, it is very evident that only one machine would need be in operation. It would be better to allow the load on one machine to increase to its full capacity before starting another machine than to divide the full capacity of one machine between two machines, whether connected in parallel or not. A machine that is running at its rated capacity has a greater efficiency than when running at a reduced load. If one machine can deliver all the current necessary, besides the gain in efficiency, it is clear that there can be no good reason for running two, which would simply mean extra wear on the moving parts, extra lubrication, and the extra attention necessary from the dynamo tender.

When the current necessary increases above the capacity of one machine, then it is obvious another machine must be connected in circuit. Suppose 1200 amperes were called for; this could be delivered by one machine at its full capacity of 800 amperes, and by a second machine running independently at 400 amperes. The case now becomes different, for two generators are necessary and whether running singly or in parallel, the wear and tear, oil consumption, and attention are practically the same. One would be running at its highest efficiency and the other at a considerably

reduced efficiency. If any extra load was called for, it could only be thrown on the light loaded machine and this would involve extra care on the part of the tender that is not necessary, that of picking out the right bus bars to throw the switches on. This is a very slight matter, but it involves at least a question of time. If the two generators are connected in parallel, the total load of 1200 amperes could be equally divided between them, so each would take 600 amperes and the combined efficiency would be greater than when one is running at its highest and the other at a reduced efficiency. If extra load was now called for, it is immaterial on which bus bars the switches are closed, for all being in parallel any increase will be equally divided between the two machines. When the load is equally divided, there is a general balancing all around of the electric energy; no one part is being strained while another part is subjected to little or no strain; the engines of the generating sets are doing an equal amount of work; there is the same amount of loss in the field regulators, and the same heating effect in all the parts of the generator. Any sudden call for current falls on both machines alike and the evils, if there are any, of sparking and consequent shifting of the brushes are on each machine reduced by half.

The two machines should be kept in parallel until their combined capacity is equal to the current called for, and if that still increases, a third machine should be connected in parallel with the other two. If 1800 amperes were required it could be furnished with two machines in parallel, each producing 800 amperes, and the third machine would then only have to supply 200 amperes, but if all three were connected, there would be 600 amperes on each, and there would be no danger of overloading any one machine, any current being added now being divided equally between the three.

Connecting Shunt Machines in Parallel.

There is no difficulty in running shunt generators in parallel, all that is necessary is to be sure to have the correct terminals connected together. The chief precaution to be observed is that when an additional generator is to be switched into circuit its field should be fully excited and the armature running at full speed before it

is connected to the mains; otherwise the current from the mains might prevent the building up of the field and the induction of current.

Suppose it is required to couple in parallel a shunt machine *B* carrying no load with another machine *A* carrying load, and that both are adjusted to the same terminal or switchboard voltage. The fields of both are fully energized and equal and the speeds relatively the same, so the *total* E. M. F. developed by the two armatures is the same. This total E. M. F. is equal to the terminal voltage plus the volts lost in overcoming the resistance of the armatures, in each case being equal to $C_a r_a$. When coupled in parallel so that *A's* load is one-half what it previously was, the armature current is halved and the lost volts in *A* are now only half as great as before. Consequently *A's* terminal voltage will rise by the amount of half the original lost volts.

The lost volts in *B* when running unloaded are equal to the field current times the armature resistance and are negligibly small. After coupling *B* now has half the original current and the lost volts increase to a value equal to the lost volts of *A*, and in consequence the terminal voltage of *B* will fall.

Under these conditions, *A* would have a higher terminal voltage than *B* by an amount equal to the original lost volts of *A*, and *A* would still have the whole load and though *B* was in parallel, it would still be unloaded. If this difference existed in two machines that were each carrying approximately the same load before putting in parallel, the double load thrown on the one would produce serious results in heating and sparking if the circuit breakers did not properly function to open the circuit.

The above discussion presupposes equal speeds, though if one was heavily loaded it would probably slow down and if the resulting difference of terminal voltages was not too great, the engine governors might act to adjust the speed to bring the voltages within limits that the machine would take their equal share of load.

Before throwing in a machine in parallel with another, in addition to seeing that the polarity is the same in each, the terminal voltage of the one to be coupled should be 2 to 3 volts higher than the one carrying the load.

Connecting Series Machines in Parallel.

Two series machines cannot be directly connected in parallel without some additional connections. If they were connected simply in parallel they might function if the E. M. F. at the terminals could be kept the same, and the internal resistances of each were exactly equal, but this could hardly occur. If the E. M. F. of one fell the slightest, current from the other would flow through the series coils in the opposite direction tending to weaken the current still more and reverse the polarity and in the end finally running it as a motor. To obviate this, not only the terminals of the machine are connected in parallel but the *brushes* are also connected by a conductor called the *equalizer*. If now either generator tends to slow in speed, current from the other will flow through the equalizer and through the series coils in the same direction as that of the generator itself, thereby building up the field and increasing the E. M. F. This equalizer also prevents any reversal of polarity, a very necessary precaution in parallel running.

Connecting Compound Generators in Parallel.

The only trouble in connecting compound generators in parallel arises from the series coils, the shunt being connected directly in parallel without any other connections, exactly as in the case of shunt generators. The series coils are connected with an equalizer exactly as in series generators, so for compound generators, it simply amounts to connecting the brushes of same polarity together as well as connecting the terminals.

Necessity of an Equalizer.

The equalizer helps to divide the load more exactly among the different machines. If there were no equalizer, as seen in series machines, the current from each armature would flow through its own series coil. When the load is increased, it might happen that one machine, being a little more sensitive than another, would take more than its share of the load, and this extra current going through its series coils would strengthen its field and cause it to generate more and more current, until it might blow its fuse and

open the circuit. Another reason is given under the connection for series machines, that is, the difference of E. M. F. whereby one would tend to run another as a motor.

Equalizing the Load.—By coupling all the machines to the equalizer so that there is a common connection between the armature and the series coils, the currents from all the armatures unite and then divide among the different series coils. If one armature tends to deliver more than its proportion of the whole current, it strengthens the current in the series coils of all the machines and

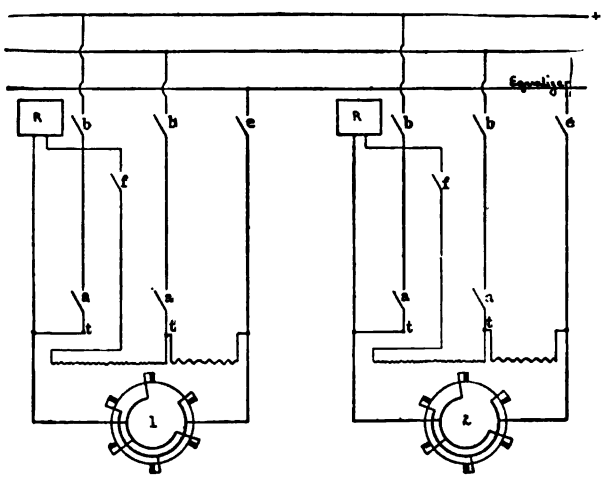


FIG. 85.—Parallel Connections.

not its own alone. If one tends not to take its full share, some of the current from the other machines goes through its series coils and helps build up its field so that it delivers more current.

Operating in Parallel.

Fig. 85 shows the connections of a modern generator to the bus bars on the switchboard. *R* shows the rheostat in series with the shunt field, a field switch *f* being introduced in circuit.

On the headboard there are two single-throw switches, one for each pole of the generator, represented by *a, a.* In addition, not

shown, there is a double pole circuit breaker and a switch for shunting the series coils or for short-circuiting the series coils. On the switchboard, there are independent bus switches shown at *b, b,* for connecting the generator leads to the bus bars. The common equalizer bus bar is shown under the current bus bars and to it is connected the equalizer from each generator through equalizer switches on the switchboard, shown at *e, e.*

Suppose No. 1 is running singly and delivering current to the bus bars, then all the switches *a, a, b, b,* and *f* would be closed. It is desired to connect No. 2 in parallel with it.

1. See all the switches on No. 2 open; these are, from the figure, the headboard, equalizer, bus bar switches, and field switch.

2. Close equalizer switch *e* on No. 1.

3. See that the resistance in field rheostat is turned to point marked "Low," all resistance out.

4. Close the shunt field switch *f.*

5. See that the voltmeter is connected on terminals for No. 2.

6. Start engine and bring it up to speed (shunt field being energized, E. M. F. will build up, and there being no resistance in rheostat will rise rapidly).

7. Move rheostat arm till E. M. F. rises considerably above the normal and then move it until it is about 2 volts above the normal.

8. Close equalizer switch *e* on No. 2.

9. Close bus bar switches on buses on which it is desired to run.

10. Close right-hand switch *a* on headboard. (This must be the one that has the series field.) This excites the series field through the equalizer from the other machine.

11. Close left-hand switch on headboard. (The one opposite to that which has the series field.)

12. Regulate load by field rheostat.

To cut out a machine that is running in parallel with another, the opposite method of procedure is followed.

1. Trip circuit breaker. (It is not necessary to open the headboard switches independently.)

2. Open bus bar switches.

3. Open equalizer switch.

4. Turn rheostat and when voltmeter stops moving toward zero, open field switch.

5. Stop the engine.

NOTE.—For operating in parallel with standard switchboard, see under standard switchboard, Chapter XXIII.)

In the switchboard that was the standard for many years (Fig. 266) to connect in parallel, it was only necessary to see that the machines were poled alike, that they had the same E. M. F., that the load was approximately divided by means of the circuit switches, and the equalizing switch closed. Closing this switch, which is a double switch, connected one set of mains in parallel and connected the equalizers from each generator, the other set of mains being permanently connected. The load was afterwards adjusted by the shunt field rheostats.

CHAPTER XIV.

SERVICE GENERATORS.

A generating set is a combination of an electric generator and its operating motive power. Generating sets used in ships of the navy consist of the generator and engine directly connected, so that both the engine and generator armature make the same number of revolutions. Up until very recently the motive power has been steam through the agency of the ordinary reciprocating steam engine, but at the present time, steam, through the agency of the turbine, is being utilized.

Although the generator and its engine are considered as a unit in ship installation, their characteristics will be considered in different chapters.

General Characteristics.—The general type of generator might be described as *direct current, constant potential, multipolar, compound wound;* this at once describing the type of armature winding (closed coil), as well as type and winding of the field. In the early days of electric installation on ships of the navy, a small bipolar machine was used, and this type may be found on a few vessels not built according to government specifications, and commercial generators of various designs may be met with in naval auxiliaries and colliers. All vessels built by or for the government are supplied with standard apparatus, built under specifications prepared by the Navy Department.

The size of generators has steadily increased to meet the demands for increased power, and the increased current has necessitated new designs of armature winding, of armature conductors, new forms of frame and pole pieces, and a greater division of the magnetic field, and new designs for brush and holders to accommodate the increased number of brushes occasioned by the increase of current. From a small machine of 5 kilowatts power at 80 volts, generators

have grown to a size capable of delivering 2400 amperes without overload, so that a machine that may be considered a standard for a number of years is soon superseded by one of another design.

Forms of Field Magnets.

There are several forms of these to be found, depending on the standard at time of installation, and figures of representative types are given.

General Requirements.—Whatever the form, the material must be of the highest permeability, the greatest cross-section for a given weight, and of the softest iron consistent with mechanical strength and with the fewest number of joints. For small generators the frame is frequently of wrought iron, but in the larger sizes the lower part usually forms part of the generator frame or foundation, requiring it to be of cast iron or cast steel.

Fig. 86 represents a type designed particularly for ships' use and called the Marine Generator, and it may be found on vessels built from twelve to fifteen years ago. This arrangement of pole pieces and field frame was particularly unusual, there being four *internal* and four *external* poles, and the winding of the field conductors was in one continuous coil on the side farthest from the commutator, and between the pole pieces. The idea of the internal poles was to allow induction in the inner portions of the armature conductors, as in the ordinary form of external poles only the outer portion is available for cutting lines of force. This peculiar arrangement only permitted the armature to be supported on one end of the shaft and though electrically it was correct in principle, in mechanical construction it was bad, and there were many instances of the sagging of the unsupported end of the armature, causing it to strike the pole pieces and break the insulation of the conductors.

Fig. 87 represents a type also exhibiting peculiarities in construction, for in this the frame was built up of bars of iron instead of being solid, the idea being to get rid of the eddy currents induced in the frame and pole pieces. This was soon abandoned, for the difficulties and cost of construction outweighed any advantage gained by overcoming the eddy losses.

Fig. 88 represents a type to be found in many vessels and exhibits good electrical properties, the frame and spool cores being all cast in one piece. The field spools are then slipped over the field cores and a curved pole piece bolted on. In this form there is very little

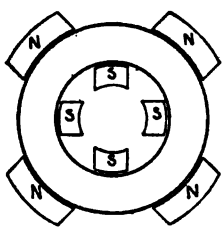


FIG. 86.

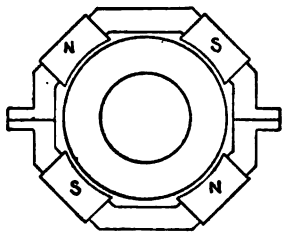


FIG. 87.

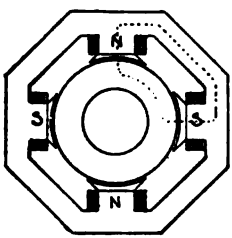


FIG. 88.

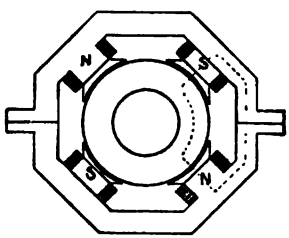


FIG. 89.

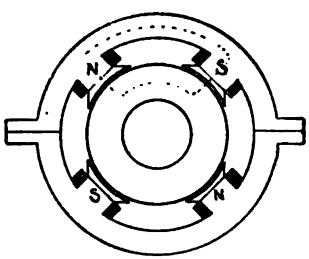


FIG. 90.

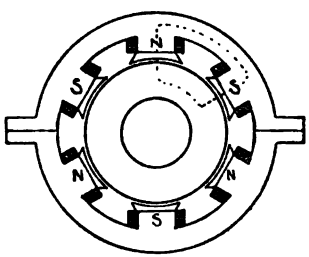


FIG. 91.

stray field, the four magnetic circuits as shown by the dotted lines being compact and there are no joints to increase the magnetic resistance. It has the disadvantage of requiring the armature to be removed before any spool can be taken off for examination or

repair, while the lower spool became the natural receptacle for dirt falling to the bottom. This spool frequently gave way in its insulation due to the dampness and oil that naturally found its way there. To get rid of these disadvantages the type represented by Fig. 89 was adopted.

In this type all the field spools are more easily accessible, and the field frame being jointed in the middle, the upper part with its two spools can be lifted without disturbing the armature. This is a particularly good form and was a standard for a number of years.

Fig. 90 represents a type that is used on a few of the smaller vessels, and is only different from Fig. 89 in the circular form of the frame and it possesses all the advantages of the other.

Fig. 91 represents a type used on a few of the more modern generators and is different from the others in that the number of poles is increased. This is used on machines of large capacity or from which large currents are drawn, the total magnetic flux being divided into six separate magnetic circuits as shown by the dotted lines. The induction is divided among them and the loss is smaller than with a smaller number of magnetic circuits. The field is better balanced and the armature reactions are much lessened. It increases the number of brushes but this is a necessity on account of the large currents.

Armatures.

Under this head are included the **armature core**, the **windings** and the **commutator** ready for operation. For several years the standard armature for service generators was a modification of the Gramme-Paccinotti ring, a section of the ring in the direction of its length showing rectangular areas, and perpendicular to this direction a ring form. Fig. 92 is intended to show some of the details of construction, though not of any one particular type, as the different types had their own peculiarities of mechanical construction.

Core.—The armature core is built up of thin laminations of soft iron, punched or cut to shape, each piece showing as a circular disc with a piece punched from the center. Their usual thickness is about one millimetre, the end ones being thicker to allow a good

holding surface for the frame that holds them in place. The laminations are of the softest iron in order to reduce hysteresis loss as much as possible, and if they have been punched, they are afterwards annealed before final assembling. At the first assembling on the frame they are put in a lathe and turned smooth with a fine tool, and afterwards ground finer with fine files or by emery wheels. As in this style armature, conductors are wound directly on the core, it is necessary that there should not be any small burrs or uneven surfaces left to cut the insulation of the conductors. Before final assembling the laminations are treated with a coat of enamel, and this need be but very light as the insulation is simply intended to reduce the eddy currents, and the lightest insulation is sufficient to confine them to their own individual lamination.

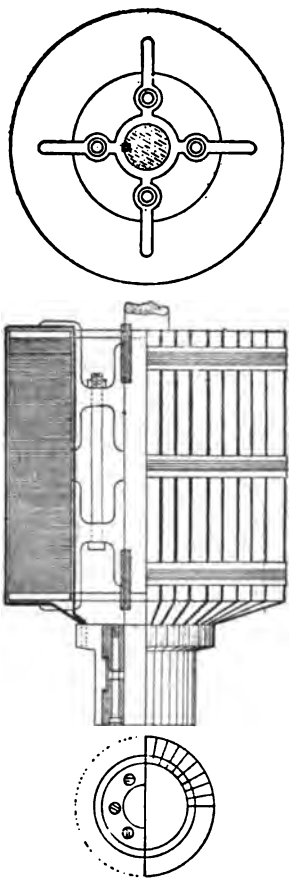


FIG. 92.—Ring Armature.

The laminations are finally assembled on a spider frame shown in the cross-section in the figure. The two ends of this frame are drawn together by bolts from one web of the spider frame to the other and when these bolts are set up, the laminations are drawn tightly together. In some cases, the laminations are pressed together by hydraulic pressure and then held by the frame. The object in having the frame bolts through the frame and not through the laminations is to reduce any eddy currents that might be induced in them, being placed inside the core where there is no magnetic field. The frame is of some non-magnetic material, bronze or gun metal, and is insulated from the end pieces, while the whole core is insulated with paper and mica before the conductors are wound on it.

Securing of Frame to Armature Shaft.—The spider frame is secured to the shaft by keys at each end imbedded in the shaft and frame, and it butts against a shoulder turned on the commutator end of the shaft and held against it by a locking nut on the other end of the frame.

Cross-Connections of Armature.—In the four-pole machine, where there are two diameters of commutation, four sets of brushes would ordinarily be required, but by cross-connecting the armature, only two sets are necessary. By this is meant the connecting of opposite segments of the commutator with conductors, these being soldered into opposite segments all the way around the commutator on the end nearest the armature. The function of these cross-connectors is to carry the current from the segment where a brush would have to be placed if not cross-connected to the segment on which the brush is resting. This connecting diametrically across the commutator brings the two sets of brushes used 90° apart.

Conductors.—In the armatures that were standard for several years, the conductors are made up of stranded copper wires and the sizes calculated for an overload of 50 per cent. The stranded conductors are more flexible and the operation of winding the ring is made easier than if they were solid wires. The conductors are wound on the smooth core, forming a ring winding, after the core has been enameled and covered with heavy cotton and the latter shellaced or varnished and then thoroughly dried at a high temperature. In generators of this type in the smaller sizes, the conductors are laid in two or more layers on top of one another, but in the largest size, one layer was sufficient. The number of complete turns around the core for each segment of the commutator depended on the capacity of the generator and varied with their size, but were always laid to make a smooth surface on the outside of the armature.

Connectors to Commutator.—There are no independent connectors from the armature conductors to the commutator, the conductors themselves being brought down and soldered solid into their proper segments, a hole being bored in the raised part of the segments for this purpose. They are pointed from the armature side of the commutator and the bared wires fitted into the holes

bored for them, and then soldered solid, so that the ends may be seen solidly connected.

One or two forms of small generators have the connectors screwed on top to the commutator segments.

Binding Wires.—After the armature is completely wound, the conductors are further secured on the core by binding wires, placed at equal intervals along the length and bound around the circumference. These wires are to prevent the conductors from being shaken loose and racked off when revolving at a high rate of speed. A strip of mica is laid on first around the circumference and the steel binding wire is wound over it, drawn taut and the ends soldered to the other turns of the winding.

Insulation of Conductors.—The conductors are thoroughly insulated, dry cotton soaked in shellac being used and put on double, and in some cases the strands themselves are insulated in like manner one from another.

Commutator.—There is not much difference in the commutators of the different types of the generators in use except as to size. They are made up of as many segments as there are separate coils on the armature, in some cases being as high as 350.

The segments are made either of phosphor bronze or hard solid drawn copper of the highest conductivity. These are made to the proper shape and dimensions, each being of a cross-section of a sufficient size to carry the greatest current. The cross-section and the dimensions of the insulating material determine the diameter of the commutator. The segments are made slightly tapering in their width in order that the insulation may be of the same thickness throughout their depth. The insulation consists of several thicknesses of mica tightly pressed together, the segments and insulation being made of considerable greater diameter than the finished dimensions, both of them being turned down in a lathe and the whole surface smoothed with fine files and emery paper and then polished.

The segments are held in place and prevented from flying off due to the centrifugal force of the rapidly revolving armature by collars which fit around the shaft and provided with projections or inclined shoulders that fit into similar shoulders made on the

inside of each commutator segment. Bolts pass through these collars and on being set up, they tightly press the segments and hold them securely in place. This arrangement is shown in the figure.

The segments are insulated with mica from the collars on the inside and also on the shoulders, the inside face usually being left clear of the outside of the collars, but, in some cases, also insulated.

The collars are secured to the shaft by a feather and prevented from moving along the shaft by set screws through the collar into the shaft.

Field Windings.

The conductors composing the field are wound on spools made and shaped to fit snugly over the cores which are in one with the field frame. In some cases these spools are elliptical, others are oblong, and still others are circular. They are made of hard rubber or compressed paper or fibrous matter. Each spool is wound separately, both ends of each winding being left out where they are fitted with special leads and with clamp connections for joining to the windings of adjacent spools. These special connections allow any spool to be disconnected from the others for purposes of examination, testing or repair. There are two separate windings on each spool, the series winding and the shunt winding, the windings being insulated from each other by cardboard and oiled cotton. The leads come out on opposite sides of the spool, the series leads being nearest the armature. It is immaterial which winding is put on first, but it is usual to wind the series first, being in the shape of heavy copper ribbon which readily takes the shape and lays flat and even on the inner surface of the spool.

Insulation of Windings.—The series windings are usually insulated from each other by some form of unbleached cotton, and the shunt windings are usually single cotton-covered wire.

Brushes.

The number and size of brushes depend upon the current to be carried, and in machines of large capacity, to avoid having brushes of too great a size, the number is increased. The bipolar machines require but two sets of brushes, a set of brushes being

referred to as the number on each arm of the holder. In the four-pole machines which were the standard, and in which the armature was cross-connected, two sets of brushes are necessary, placed 90 degrees apart on the commutator. In some of these machines, there were two brushes per set, in others three, and in the largest there were four.

Material.—The material is either copper or carbon, the former being used for several years, and was made up of copper gauze sheets pressed into shape. The completed brush of this material is more pliable than other forms, and there is not so much danger of the brushes cutting the commutator, due to too great tension, as the gauze easily bends. It also has the advantage of offering more collecting points for the current, as each little point does its share, this tending to reduce heavy sparking, as the whole current is divided into many little paths. The gauze form offers good opportunities for ventilation, and it does not heat as readily as some other forms.

Copper brushes are set at an angle to the normal to the commutator, the ends being beveled to lie flat on the commutator surface.

Carbon brushes are used on a great many generators and in nearly all motors. They are made in the block form, except for small motors, and are set normally to the commutator surface. As the resistance of carbon is greater than copper, they heat more easily, but on this account they are made larger than would be necessary for copper brushes. They have no sharp points, so do not scar the commutator, and if properly adjusted will soon give the dark bronze polish to the commutator that is indicative of good condition.

Brush Holders.—Brush holders may be said to consist of the rocker, rocker arm, and the brush holder proper, with the necessary springs and screw clamps for adjusting the brushes. These are of various designs and details, depending on the kind and number of brushes used, but all must fulfill certain requirements. They allow the brushes to have a motion on the brush holder arm in a direction parallel to the commutator segments, being clamped by set-screws through the holder to the holder arm. Those using copper brushes have a small motion in the direction of rotation of the

armature, being clamped by screws in any desired position. This motion can be given to any brush independent of any motion given to the holder by means of the rocker arm. All holders are fitted with springs or screws by which the brushes can be held firmly but not rigidly against the commutator, and by which the pressure against the commutator may be regulated. Most forms are fitted with "hold off" catches by which the brushes may be held clear of the commutator.

After each brush is adjusted by its set and clamp screws and regulating spring, all the brushes together may be moved in a direction around the commutator by means of the rocker arm, through which motion is conveyed to the rocker and from that to the brush holders and to the brushes. The rocker arm can be secured in any position by means of a locking screw and the brushes held in any desired place.

In the four-pole cross-connected armature the rocker consisted of a bronze frame in the shape of a quadrant of a circle, the holder arms being secured at right angles to it 90 degrees apart on the holder. The rocker arm was a straight spindle with a wooden or rubber handle, passing normally through the edge of the rocker, its central end being fitted with a thread which could be set up against the bearing on which the rocker turned. To move the brushes, it was only necessary to turn the rocker arm releasing the threaded end, and then moving the arm radially around the commutator.

The holder arm is insulated from the rocker by hard rubber discs and cylinders, the generator leads being secured to the holder arms where they are secured to the rocker.

Headboards.

Standard machines of some years ago and of which many remain were fitted with wooden headboards, resting on the top piece of the octagonal framepiece. The current from the brushes is carried to terminals on this headboard by flexible bus conductors. From the headboard current is carried to the switchboard through a double-pole switch. There are separate terminals for the shunt and series windings, so either may be disconnected for

purposes of testing or repair, and, in addition, there is a separate terminal for the equalizing cable which connects through the switchboard to corresponding terminals of other generators. There is a separate terminal for the leading wire to the shunt field regulator, the other end securing to one of the shunt terminals. From the shunt field terminals were taken off connections for a pilot lamp over the headboard, which would glow while the main switch is still open, due to E. M. F. of the shunt current. This pilot lamp is useful as a means of telling when the field is commencing to build up and also insures light in the dynamo-room in case the main fuses blow or circuit breaker trips.

Back of the headboard and secured in a wooden case is a variable resistance of heavy ribbon German silver connected as a shunt to the series winding. This is for the purpose of finally adjusting the E. M. F. in compounding the generator, and when once adjusted should not be further altered. It is usually in a locked case covered with a gauze top made for purposes of ventilation.

Type M. P. 6-32-400-80.

This type of generator is known as multipolar, 6 poles, 32 kilowatts, 400 revolutions, 80 volts. It is a direct-current type and wound compound with long shunt connection. A detailed description of this generator is given, partly because there are many of this type installed and partly because it is a good sample of a modern generator, but chiefly to illustrate the general characteristics of all generators, and to show the method of insulation and the care taken to prevent magnetic and electrical losses. If one is entirely familiar with such a generator, the understanding of others is made easier, and one should not be at a loss to know how to make repairs, to wind field coils or to renew armature windings, or to know what degree of insulation is necessary or the materials to be used.

Field Frame.—Fig. 90 represents the form of field frames. The magnet frame is of cast steel and is made in two pieces, the lower of which is provided with bolts and set screws for use in securing proper alignment. The magnet cores are of soft steel of high permeability and are bolted to the magnet frame. A key which

forms part of the magnet core engages a keyway in the frame and insures perfect alignment of the pole piece.

The lower end of the magnet frame is provided with feet by which the frame is bolted securely to the generator foundation. The frame is insulated from the bed plate by a block of ash one inch thick with fiber bushings and removable washers around the securing bolts.

Armature.—The armature of this generator is distinguished from others that preceded it by being **drum** wound, of the type known as a two-layer winding. The laminations forming the core have 77 slots punched at equal distances around their peripheries, a view of one lamination showing a circular disc with 77 teeth. The laminations of the core are assembled on a spider frame of cast iron accurately fitted and keyed to the shaft. The spider frame is made with flanges which project on each end beyond the laminations. The armature conductors are made of copper bars imbedded in the slots and run the entire length of the frame. Beyond the laminations and on the flanges the conductors are bent, and as there are six poles, each conductor is connected to one approximately 60 degrees around the circumference from it. The general form of a conductor is shown in Fig. 93.

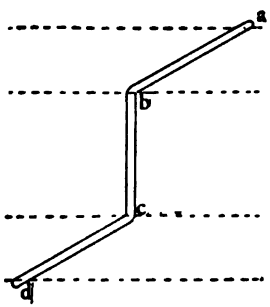


FIG. 93.

In this figure, the conductor is represented by *a, b, c, d,* the part *b, c* being imbedded in the slot, and the portions *a, b* and *c, d* on the flanges. These portions are bent to join the bent portions of other conductors around the armature to make the drum winding. On the end farthest from the commutator, the ends of the conductors are simply joined together; on the commutator end they are connected at their junction to the commutator segments.

There are two layers of conductors in each slot, but as the layers from two slots are joined, although there are 154 conductors, there are only 77 connections on the front end, making 77 segments to the commutator. On the front end, an inner layer is connected to

an outer layer 60 degrees from it, and on the rear end an outer layer is connected to an inner layer. The general plan of wiring is shown in Figs. 94 and 95.

In Fig. 94 the full lines represent the bent portion of the conductors on the commutator end, the dotted lines on the rear end. The numbers on the outside of the circle are the number of the slots, those inside the number of the conductors, being 154 in all, two to

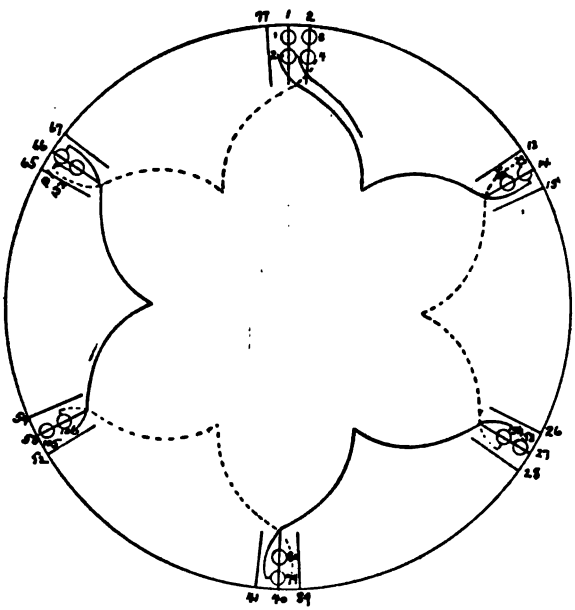


FIG. 94.

each slot. This winding makes a closed coil, the winding continuing through all the layers and ending at conductor 2, the starting point. Fig. 94 shows an inner layer joined to an outer layer, the outer layers of course being on top all the way around the circumference.

Core.—The core consists of thoroughly annealed electrical sheet steel, 24 inches in diameter and .025 inch thick, the discs being magnetically insulated from one another. Inserted between the

laminations at intervals are space blocks, which are for the purpose of providing air ducts which communicate with the interior of the armature for cooling the core and windings.

The bolts through the spider frame holding the laminations in place are secured so as not to pass through the laminations.

Armature Insulation—Flange.—The flanges are insulated, first with a layer of muslin, then three layers of red paper and two layers

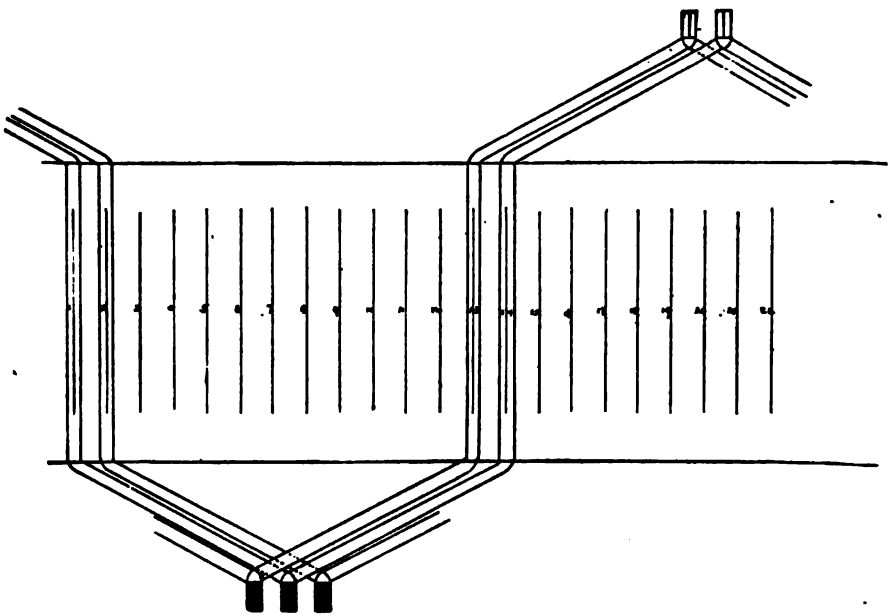


FIG. 95.

of oiled cotton, arranged alternately, and over all another layer of muslin. Over this last, layers of pressboard are placed and the flanges built up flush with the bottom of the slots in the laminations. The insulation, with the exception of the pressboard, is carried over the edges of the flanges where it is pasted down.

Slot.—In each slot in the lamination, the insulation consists of two layers of red paper and two of oiled cotton, arranged with the paper outside and the oiled cotton inside next to the conductors. This completed insulation, which is 0.35 inch thick, is held together

with shellac, and is of sufficient size to project above the conductors when they are in place and to fold over the top, and to project beyond the ends of the slot a sufficient distance to break joints with the flange insulation.

This insulation is pressed into the slot before the shellac becomes dry. There are two parts of a coil in each slot and the insulation between them is red paper or leatheroid, cut slightly wider than the slot and pressed into place.

The spaces between the upper and lower portions of the coils beyond the slots in the laminations on the flanges are filled with pressboard overlapped at the joints.

After the coils are in place, the slot insulation is folded over the top of the conductors and in the notches in the upper part of the slots are driven hard wooden wedges, made of ash.

Conductors.—The armature winding consists of 77 coils, each coil made of two bars .15″ × .444″ in multiple, with no insulation between the bars. The coils are insulated with cotton tape .009 inch thick, put on ½ lap and then dipped in insulating japan and baked. There are two layers in each slot.

Connectors to Commutator.—The commutator leads are of flexible copper, .04″ × .75″, bent so as to clamp the armature winding and firmly soldered into slots cut in the segments of the commutator.

Binding Wires.—These are No. 13 B. & S. phosphor bronze wire. There are four bands, twelve turns per band, two over the front and two over the rear flange. Leatheroid is used between the binding bands and the winding.

Commutator.—The commutator segments are supported on a shell which is directly attached to the spider. The bars are of hard drawn copper with insulation of selected mica not less than .03 inch thick. The bars are in line with the shaft and are secured by bolts and clamping rings. These bolts are accessible for tightening and removable for repair. The width of the commutator is 12 inches, the size of the segments on the circumference .7 inch, and depth of segments .75 inch.

Field Windings.—The field spools for this machine are circular in shape and the series and shunt field coils are wound separately on the spools. The field spools are made of malleable-iron flanges

riveted to a sheet-iron body. There are three sets of series and shunt coils, three being wound in one direction and three in the other. The spools are held in position by projecting pole pieces upon the cores which are bolted to the magnet frame.

Spool Insulation.—In this description, the cylindrical part of the spool is called the shell, and the two circular discs the flanges. The spool flange is first insulated by maple veneer board collars which are finished with one coat of japan, two of black shellac, and one of varnish. Before the collars are put in place, each end of the shell next the flange is insulated with four layers of muslin tape. The collars are then forced over this insulation to make a tight fit, any space between the edges of the collars and the insulation being filled with asbestos fiber which is afterwards saturated with boiled linseed oil. After the collars are in place, the shell is covered with four layers of oiled tape, two layers of oiled cotton and two layers of red paper and a final layer of oiled tape. This insulation is cut the exact width of the space between the collars, and the last layer of tape is wound so as to well fill the corners and extend about $\frac{1}{4}$ inch up on the collars. After the winding is in place, the outside wires are japanned. The external diameter of the collars is greater than that of the flange, and where it projects over the flange it is rounded to give it a finish.

Series Winding.—The series winding is wound on the insulated spool first and it consists of $4\frac{1}{2}$ turns of sheet copper, in three strips, wound in multiple. Two of these strips are $.05'' \times 5''$ and one $.04'' \times 5''$, and they are insulated from each other by unbleached percale of sufficient width to overlap the edges of the strips.

The series leads for connection to the adjoining spools are made of copper strips $.075'' \times 3''$, and are brought out next the flange nearer the armature and separated from the shunt winding by an insulating pad consisting of two thicknesses of varnished cambric and two thicknesses of red paper, extending $\frac{1}{2}$ inch on each side of the series lead and $\frac{1}{2}$ inch above the shunt winding. The leads are riveted and soldered to the series windings and should be brought out exactly diametrically opposite one another, and lead out along the insulating collars.

The weight of each series coil is about 24 pounds, and with a cold resistance of .000105 ohm.

Shunt Winding.—The shunt winding is placed on the spool over the series winding, the two windings being separated by a pad composed of oiled asbestos, carboard, and oiled cotton. This winding consists for each spool of 725 turns of No. 9 B. & S. single cotton-covered wire, the whole weighing about 80 pounds, and has a resistance of about 1.58 ohms.

The shunt leads are brought out on the flange away from the armature, and consist of two strips of copper, each .025″ × .875″. These terminals come out on the side of the spool towards the engine. The inner terminal is soldered to the wire by solder and rosin dissolved in alcohol. The outer terminal is secured under the last six turns of the winding. The last four turns are soldered to the terminal and the last two are soldered all the way around. The outer layer is coated with japan to preserve the coil from moisture.

Series Shunt.—This is a resistance connected across the series leads of the generator, being made of several strips of German silver. When this is connected as a shunt to the series a portion of the main current flows through it. If its length is increased or cross-section diminished, its resistance is greater, and more of the total current will flow through the series windings, increasing the field. Increasing the cross-section or decreasing its length has the opposite effect, so by this the compounding of the generator can be regulated. When once adjusted for any particular range of voltage it should not be disturbed.

Brushes and Holders.—In this generator, the commutator is not cross-connected, necessitating six sets of brushes, and in each set there are four brushes and four holders, these four being mounted on one holder arm. Fig. 96 shows the details of one brush and holder, all the others being identical with it. Carbon brushes are used, 1¼″ × 1¼″ × 2½″ in size.

The brush *F* is shown resting on the commutator and fitted in the box *A*, which is secured to the arm *H*, which in turn is secured to the arm *G* connected to the rocker. The brush is held down on the commutator by the flat copper spring *I*, on which is another flat copper spring *B*, resting on *H* and held by the screw-thread *K*. The top of the brush is connected to a pigtail connector *E*, a copper

conductor, which is clamped under a nut on the spring *B* at *L*. Tension on *B* and *I* is given by turning the milled head *C*, and by screwing that down the brush is held firmly against the commutator.

The pigtail connector allows a free movement of the brush in the holder and avoids the resistance of imperfect contact that might exist between the brush and its box.

To Renew Brushes.—To take out a brush, unscrew the stud *D* which frees the nut clamping the end of the pigtail connector *E*, and allows that end to be withdrawn through slots cut in *B* and *I*. Push the spring *I* forward, which will allow the connector to be easily withdrawn. Both springs *B* and *I* can then be pushed to one

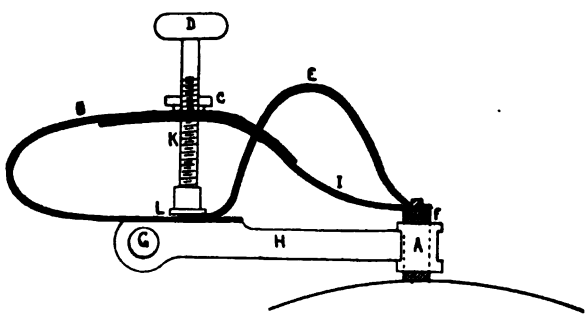


FIG. 96.

side over the head of the brush, which can then be lifted out. In putting in or taking out a brush, it is not necessary to change the tension given by *C*, so the pressure on *B* and *I* need not be altered after once adjusted.

Rocker.—The rocker for this generator consists of a circular frame with six radial arms from the central bearing which turns on the commutator bearing. This rocker looks somewhat like a steering wheel, and to each end of the six radial arms is secured an arm at right angles to it holding the brushes, of which there are four to each arm. An extra spoke of this circular rocker is made with a handle, the central end fitted with a thread, which screws through the hub of the wheel to the bearing on which the rocker turns. This allows the frame to be turned and locked in any posi-

tion. The brushes are three positive and three negative, alternately arranged around the commutator, the three positive ones connected in parallel and the three negative ones in the same manner by connecting pieces in the form of arcs of circles.

Form D Generator.

This type of generator is the latest made under the standard of 80 volts, all later ones being designed for 125 volts. It is known as M. P.-8-32-400-80 Form D, and is directly connected to the type of engine referred to under the chapter on Motive Power for Generators, as 7½-12 × 8 Cross Compound, Form H Engine.

Its principal difference from the type previously described is in the frame and poles, in the arrangement and connection of brushes, and in the headboard. The frame is circular in shape, divided longitudinally in its middle and so arranged that the upper half can be lifted clear of the armature. The lower half is fitted with two lug feet to secure it to the bed plate.

There are eight projecting poles arranged equally around the frame, fitted as previously described, and so spaced that one does not come in the vertical line through the center of the shaft, but at an angle of 22½° from the vertical. Eight poles necessitate eight sets of brushes and four carbon brushes are fitted to each set. The brushes are held in holders from which project radial connecting leads to the connecting arcs. These arcs consist of two connecting bars of copper, of opposite polarity, almost the diameter of the field frame, fitted concentrically with the shaft, one behind the other. These arcs are of 270°, overlapping 45°. Every other set of brushes is connected to an inner and outer arc respectively, connecting four alternate sets of brushes to one arc, the other four to the other arc.

The connecting arcs are secured to and insulated from a circular rocker piece, one face securing the arcs, the other resting against and fitting in a groove in the edge of the field frame. This rocker piece is made light by cutting elongated holes in its side face. By revolving this rocker piece in the groove, both arcs and consequently all the brushes are moved circumferentially around the commutator.

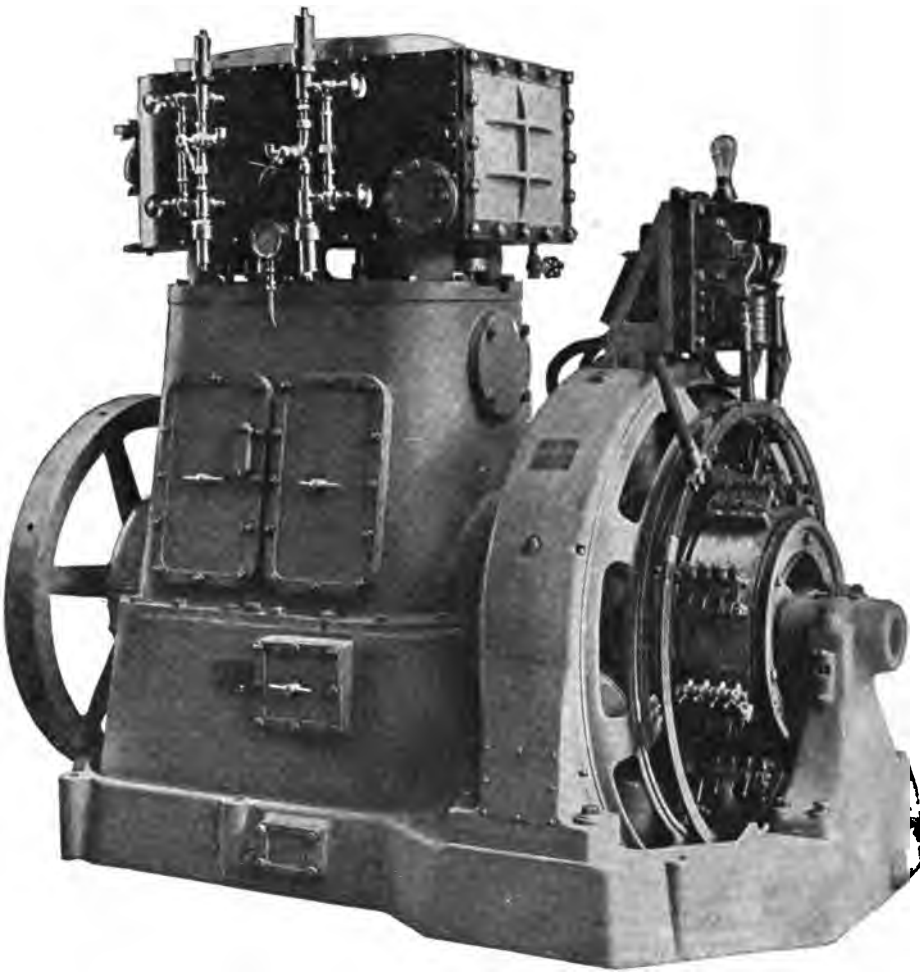


FIG. 97.

M. P.-8-32-400-80 Volt. Form D. Generating Set with 7½-12 x 8 Cross Compound, Form H, General Electric Engine.

Motion is given this rocker by a hand wheel fitted with gearing let in through the magnet frame, and also fitted with a locking wheel to lock the rocker in position.

Headboard.—The generator leads are flexible conductors, one leading from each arc to the headboard. The headboard is fitted with single-pole circuit breakers, one in each lead, entirely independent of the other, with terminals for the shunt winding and its regulator, with a switch for short-circuiting the series winding if desired, with a pilot lamp, and with three terminals leading to the switchboard, one for each generator lead and one for the equalizer lead. On the back of the headboard is the usual series shunt.

The headboard is secured to a frame mounted on the magnet frame directly over the armature.

Most of the above details of this generator may be seen in the photograph shown in Fig. 97. This is shown connected to a Cross Compound, Form H, General Electric Co. Engine, described in the chapter on Motive Power for Generators.

M. P.-6-16-450-125 Volt Type.

This is one of the latest type of generators designed for ship installation and is built under the following specifications of the Bureau of Equipment, Navy Department:

Specifications.

Generator.

1. To be of the direct-current, multipolar type, compound-wound long-shunt connection, designed to run at constant speed and to furnish a pressure of 125 volts at the terminals, at rated speed with load varying between no load and one and one-third times rated load.

2. The magnet yoke or frame to be circular in form, to have inwardly projecting pole pieces, and to be divided in half horizontally, in all generators above 5-kilowatts capacity, the two halves being secured with bolts, to allow the upper half with its pole pieces and coils to be lifted to provide for inspection or removal of armature. Pole pieces to be bolted to frame, bolts to be accessible in assembled machine to enable removal of field coils without disturbing armature or frame. Magnet frame to be provided with two feet of ample size to insure a firm footing on the foundation.

3. Facilities for vertical adjustment of frame to be provided in sizes of 16 kilowatts and above

4. Armature spider to be designed to avoid shrinkage strains. To be accurately fitted and keyed to shaft and to have ample bearing surface thereon.

5. The discs or laminations to be accurately punched from the best quality thoroughly annealed electrical sheet steel, slot to be punched in periphery of laminations to receive armature windings. Discs to be magnetically insulated from one another and securely keyed to spider or held in some other suitable manner to obviate all liability of displacement due to magnetic drag, etc. Space blocks to be inserted between laminations at certain intervals to provide ventilating ducts for cooling the core and windings.

Laminations to be set up under pressure and held securely by end flanges. Bolts holding these end flanges must not pass through laminations.

6. The commutator bars or segments to be supported on a shell, which must be either part of or directly attached to the spider, to prevent any relative motion between the windings and these segments. Bars to be of hard drawn copper finished accurately to gauge. Insulation between bars to be of carefully selected mica and not less than 0.03 inch thick, and of uniform thickness throughout.

Bars to line with shaft and run true, to be securely clamped by means of bolts and clamping rings. Bolts to be accessible for tightening and removable for repair.

7. Brushes to be of carbon. In sizes over 5 kilowatts there shall be not less than two brushes per stud, each brush to be separately removable and adjustable without interfering with any of the others. The point of contact on the commutator shall not shift by the wearing away of the brush.

8. Brush holders to be staggered in order to even the wear over entire surface of commutator; the generator to be provided with some device for shifting all the holders simultaneously. All insulating washers and brushes to be damp proof and unaffected by temperature up to 100° C.

9. Finished armature to be true and balanced both electrically and mechanically, that it may run smoothly and without vibration. The shaft to be provided with suitable means to prevent oil from bearings working along to armature.

10. All copper wire to have a conductivity of not less than 98 per cent.

11. The shunt and series field coils to be *separately* wound and *separately* mounted on the pole pieces. The shunt and series coils, respectively, of any one set to be identical in construction and dimensions and to be readily removable from the pole pieces. The shunt coils as well as the series coils are to be connected in series.

12. In sizes of 16 kilowatts and above a headboard is to be mounted

on the generator containing the necessary terminals for main switchboard and equalizer connections, shunt and series field connections, pilot lamp.

13. The field rheostat is to be of fireproof construction suitable for mounting on back of switchboard, with handle or wheel projecting through to front, either directly connected or by sprocket chain, handle to be marked indicating direction of rotation for raising and for lowering voltage of generator. The total range of adjustment to be from 10 per cent above to 20 per cent below rated voltage, the variation to be not more than one-half volt per step at both full load and half load.

14. A metal name plate to be fitted to the generator in a conspicuous place, to be marked as follows:

MADE FOR
BUREAU OF EQUIPMENT
BY
(*Name of maker here.*)
CONTRACT NO. —. REQ. NO. —, 190—.
TYPE —. CLASS —. FORM —.
GENERATOR NO. —.
VOLTS, —. SHUNT CURRENT, —.
AMP., —. K. W. —.

The number of the generator to be stamped on frame near name plate, for reference in case name plate is shifted.

Operation of Generator.

15. The compounding to be such that with engine working within specified limits, field rheostat and brushes in a fixed position, and starting with normal voltage at no load or at full load, if the current be varied step by step for no load to full load or from full load to no load, and back again, the variation from normal voltage shall at no point be in excess of 2 per cent of the normal voltage of the generator.

16. The dielectric strength or resistance to rupture shall be determined by a continued application of an alternating E. M. F. for one minute.

The testing voltage for sets under 16 kilowatts shall be 1000 volts and for sets of 16 kilowatts and above shall be 1500 volts, and the source of the alternating E. M. F. shall be a transformer of at least 5 kilowatts capacity for sets of 50 kilowatts and under, and of at least 10 kilowatts capacity for sets of greater output than 50 kilowatts.

The test for dielectric strength shall be made with the completely assembled apparatus and not with the individual parts, and the voltage shall be applied between the electric circuits and surrounding conducting material.

The tests shall be made with a sine wave of E. M. F., or where this is not available, at a voltage giving the same striking distance between

needle points in air, as a sine wave of the specified E. M. F. As needles, new sewing needles shall be used. During the test the apparatus being tested shall be shunted by a spark gap of needle points set for a voltage exceeding the required voltage by 10 per cent.

17. With brushes in a fixed position, there shall be no sparking when load is gradually increased or decreased between no load and full load; no detrimental sparking when load is varied up to one and one-third times rated load; no flashing when one and one-third load is removed or applied in one stage.

18. The jump in voltage must not exceed 15 per cent when full load is suddenly thrown on and off.

19. The temperature rise of the set after running continuously under full rated load for four hours must not exceed the following:

	Method of measurement.	Maximum allowable rise in °C.
		°
Armature	Thermometer	33⅓
Commutator	Thermometer	40
Field coils	Electrical	33⅓
Shunt rheostat	Thermometer	75
Series shunt	Thermometer	40

The rise of temperature to be referred to a standard room temperature of 25° C. and normal conditions of ventilation. Room temperature to be measured by a thermometer placed 3 feet from commutator end of the generator with its bulb in line with the center of the shaft.

20. The generator to be capable of satisfactory operation for a period of two hours carrying one and one-third times its rated full load, and no part shall heat to such a degree as to injure the insulation.

21. Generators of the same size and manufacture to be capable of operation in parallel, the division of the load to be within 20 per cent throughout the range. The magnetic leakage at full load shall be imperceptible at a horizontal distance of 15 feet, measurements to be taken with a horizontal force instrument.

22. The minimum allowable efficiencies of the generators are as follows:

K. W.	Loads.			
	1⅓	1	¾	½
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
2.5	78	78	76	73
5	80	80	78	75
8	83	83	81	77
16	87	87	86	84
24	88	88	87	85
32	88	88	87	85
50	89	89	88	86
100	90	90	89	87

A sectional view of a 50-kilowatt 125-volt generator built according to the above specifications is shown in Fig. 98.

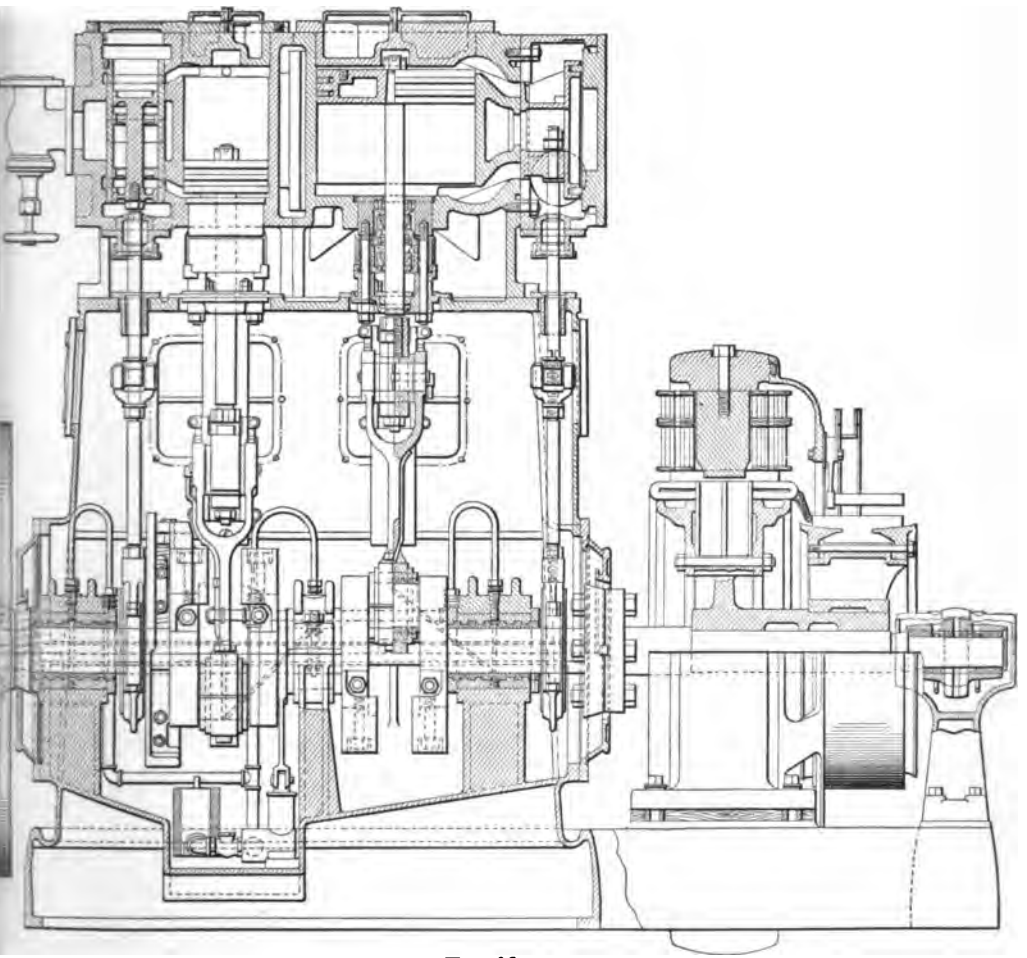


FIG. 98.

Marine Engine Cross Compound H-1, 50 Kilowatts, 7½" x 14", 7" Stroke, 400 R. P. M.

Details of 100-Kilowatt Generator.

A cross-section of the 100-kilowatt generator is shown in Fig. 99.

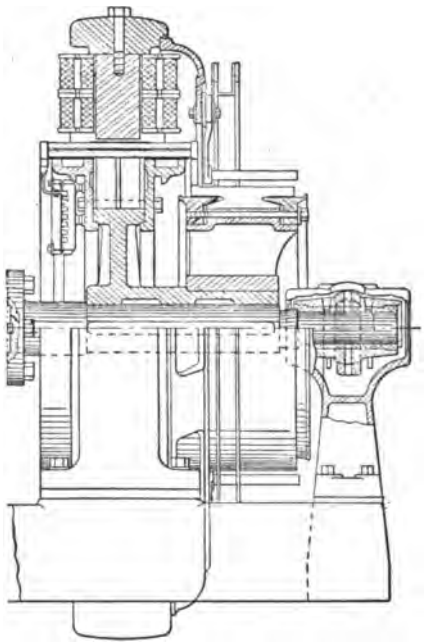


FIG. 99.—Cross-Section of 100-Kilowatt Generator.

Armature.

The armature consists of the **spider, core, commutator,** and **armature windings.**

The **spider** is a casting of cast iron, composed of a hub and six legs radiating from the hub like the spokes of a wheel. The hub fits over the shaft whose diameter on the bearing surface is 5 inches, and is driven by the shaft by a keyway and driving feather, and it fits against a shoulder on the shaft nearest the driving flange, the diameter of the shaft being increased to $5\frac{1}{2}$ inches. The legs of the spider are joined together by two cast-iron rings, one on each side of the legs, forming the rim of the wheel. These rings extend to the line of the slots in the core discs, and at the top they are

extended to form the flanges and to support the armature windings beyond the core, and on the bottom they are flanged around the T-shaped spider legs. The front and rear rings are secured by bolts passing through each and drawn together against space blocks on the core discs.

Armature Core.—Between the two rings of the spider frame are secured the core discs; the core itself of a total length of $4\frac{7}{8}$ inches is made in two sections, which are separated from each other and from the rings by space blocks. These are metal castings consisting of a ring on which are radial arms carrying the blocks. The spaces left between the sections of the core discs and the spider heads afford a system of ventilation to the interior.

The core discs are stamped from pure wrought iron and the core is built up from the discs, the laminations being .025 inch thick and are japanned for insulation before being assembled. The discs are held together by the pressure of the space block rings and are bored at the bottom for the bolts holding the spider head rings together. The core is positively driven by a key and feather on the outer face of the spider leg and inner diameter of the core. The slots for the armature windings are stamped in the discs before assembling and are afterwards trued up and made fair and smooth. Each disc is $2\frac{1}{4}$ inches thick.

The **commutator** is secured on an extension of the spider hub and fits against a shoulder made on the hub and is driven by a key. The shell comprising the body of the commutator is fitted with arms which allows air to circulate around them to the interior for purposes of ventilation. The outer surface of the shell is fitted with two rings, one on the front side, the other on the armature side, and bevelled as shown to receive the commutator bars. These rings are drawn together by through bolts, and thus the bars are held rigidly in place. The commutator bars or segments are $10\frac{3}{8}$ inches long, and there are 350 bars, two bars to a slot, and the finished diameter of the commutator is 30 inches. The bars are insulated from each other and from the shell by mica, and the ends of the bars nearest the commutator are milled to receive the connections from the armature windings.

Armature Windings.—The armature winding is of the *multiple-drum* type and consists of 1400 conductors of bar copper .07" × .075" arranged as shown in Fig. 101. Before being placed in the slots they are formed together in the Eickemeyer style of winding.

NOTE.—This consists of a series of insulated coils formed exactly alike with the portions on the flanges of the armature so formed that there will be a space between the underlying portion of one coil and the overlying portion of the other where two adjacent coils cross.

Field.

The field consists of the **frame, poles,** and **field windings.**

The details of the field are seen in Fig. 102, showing the diagram of connections.

The **frame** is circular and is a casting made in two pieces. On the lower half of the casting are cast two feet which rest on a liner on the bed plate. The upper half is similar to the lower with the exception of the feet, and the two halves are secured together by invisible bolts on each side, the bolts entering through pockets in the brackets of the feet.

The **poles,** ten in number, project inwardly from the field frame, and consist of the core over which secure the field windings, and the pole pieces or shoes. A cross-section on one pole is shown in Fig. 99.

The **core** is a cylinder of soft cast steel, fitted against the interior curved surface of the frame to which it is secured by a single bolt which is tapped into the center of the core from the outside of the frame. This permits of the easy removal of any field magnet without removing the armature. The inner ends of the core form the pole pieces or shoes and are cast solid with the core, the ends fitted concentrically with the armature.

The **field windings** are separately wound on spools which are slipped over the cores before these are secured in place and they are held by the projecting pole pieces. The shunt-winding spool goes on first, then the series. In each spool there is left an annular space for ventilation.

Brush Carrier and Connections.

The **brush carrier** consists of a circular casting with lightening holes which fits into a recess on the commutator side of the frame and secured by screws. On the upper inner side is a toothed segment which gears into a pinion on a shaft extending through the frame and which is operated by a hand wheel for varying the position of the brushes. There are two collector arcs for opposite polarity secured to the carrier, also the ten studs for the ten sets of brush holders. The brush leads for the total armature current are connected to the collector arcs and lead to hard rubber blocks secured to the top of the frame and shown in Fig. 102. One block carries the connection for the positive brush and switchboard leads and leads to the rheostat and the other carries the connection for the negative brush and switchboard leads and equalizer leads, and also lead for negative side of rheostat.

Armature Insulation.

Flanges.—Over the end of the flange is placed a layer of muslin, one end being allowed to remain hanging. Over this and extending the entire width of the flange are placed three layers of red paper, each .009 inch thick and two layers of oiled cotton, each .007 inch thick, arranged alternately, paper first. This insulation is of sufficient length to be folded over the end of the flange, where it should be pasted, after which the end of the muslin remaining hanging should be brought up and over this insulation, thus forming a finish. Over this, layers of pressed board should be placed and built up flush with the bottom of the slot.

The arrangement of the insulation is shown in Fig. 100.

Slots.—The insulation of each slot consists of one piece of .005-inch oiled red paper cut to such a size that when pressed into the slot it will project about $\frac{1}{2}$ inch above the top of the slot and $\frac{3}{8}$ inch beyond each end. After the coils are in place the insulation projecting beyond the top of the slot is trimmed off flush with the surface of the armature.

Winding.—Each bar is taped with .005-inch tape butted through the slot part and one-half lap outside of the slot. Each bar is then

brushed with shellac over the slot part and the bars forming each group are molded together, after which they are covered along the slot part with 2½ wraps of .006-inch varnished bond paper with the lap on the top. Over this is cemented a .010-inch piece of horn fiber with the edges butted in the center on the top of the coil. Between the upper and the lower layers of the winding in the slot is placed a .015-inch horn fiber separator which should project beyond the ends of the slot about ⅛ inch. Between the windings outside of the slots and over the flanges are placed .020-inch horn fiber separators, extending from the armature punchings to the inside of the clips which connect to the top and the bottom layers

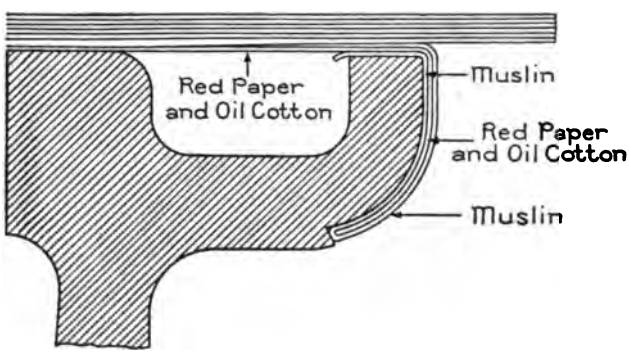


FIG. 100.—Flange Insulation.

of the winding. Over each of these separators is laid a narrow piece of .030-inch horn fiber placed close to the clips. No top sticks are used in the slots.

The commutator leads are not taped, but are given a coat of air-drying japan.

Binding Wire.—Over each section of the core are placed two bands of 10 turns each of .042-inch phosphor bronze wire, and over each flange two bands of 12 turns each of .072-inch steel wire.

Field Winding.—The series winding consists of 6½ turns per coil of strip copper $2\frac{3}{4}'' \times .075''$, arranged 5 in multiple. The weight per coil is approximately 58 pounds; the cold resistance is .000118 ohm.

The shunt winding consists of 585 turns of No. 10 B. W. G. single cotton-covered wire. The weight per coil is approximately 72 pounds, the resistance cold .78 ohm.

The two windings are placed side by side, the shunt winding being next the magnet frame.

Insulation of Field Coils.

Series Coils.—The coils are wound on forms.

Before beginning the winding, .14" of pressed board is placed around the form to allow for wrapping space.

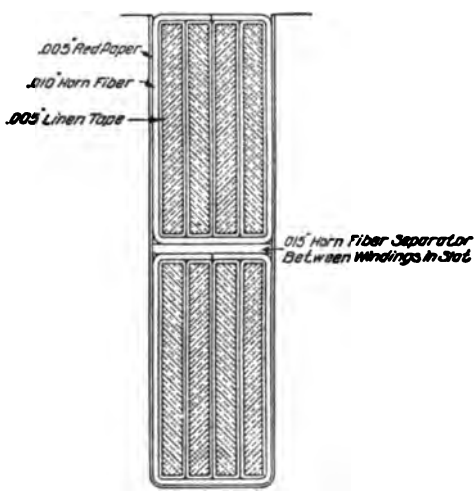


FIG. 101.—Insulation of Slot and Arrangement of Conductors.

The "I" ("inside") series lead is first soldered on and insulated with a wrapping of five thicknesses (turns) of varnished cambric, each turn being coated with shellac to hold the turns together; beneath the "I" lead are placed two thicknesses of varnished cambric to prevent the rivet heads from working through the insulation on the bottom of the coil. The winding is then begun and a piece of .030-inch leatheroid is placed between the "I" lead connection and the first turn of copper. The first two turns of copper are insulated with one thickness of .008-inch muslin

of sufficient width to lap over the top of each turn. This being done, the coil is clamped and removed from the form, and insulated by wrapping around it two layers of varnished cambric, half-lapped.

A piece of 8-oz. duck is then sewed on under the "I" lead and is of sufficient length to extend to the top of the second turn of copper, under which the coil is wrapped with one thickness of 1-inch stay binding, half-lapped; this done the coil is replaced on the form and wound with two turns of bare copper. Between these turns are placed the ventilating blocks of such thickness as will round out the coil; the winding is then resumed, the .008-inch muslin insulation being placed between the turns. Then, before cutting the copper used in the winding, the "O" ("outside") lead is riveted and soldered on and is insulated in the same manner as the "I" lead. After this there are placed under the last turn six lots of four cords each of No. 7 boot thread, equally spaced, and extending about 12 inches beyond each side of the copper.

Four of the copper strips are then cut off and the remaining strip is neatly covered with No. 2 cotton drill and wound completely around the coil, riveted to the turn beneath it and cut off, after which the coil is removed from the form. Veneer collars are then fitted to the coil and holes drilled through them at the points at which the six lots of cord are located. The collars are then tied tightly to the coil by means of the cord before referred to, after which a lacing of cord, consisting of three turns, placed around each arm in the ventilating space, is tied and cut off.

Shunt Coil.—On the form are placed two thicknesses of No. 2 cotton drill of such a width as to cover the body of the form and extend up each side 3½ inches. That portion of the drill extending up the sides of the form should be cut into small tongues of approximately ¾ inch in width; the tongues in the two layers should be staggered. To the drill is added one thickness of .020-inch pressed board, three thicknesses of varnished cambric, and one thickness of oiled asbestos. Four layers of wire are then wound on the form and the tongues of the upper layer of the cotton drill are turned down over the winding. The winding is then continued until the ventilating space is reached, when the tongues of the first thickness of cotton drill are turned down and the winding is com-

pleted to within two layers of the top of the coil. At this point pieces of cord are placed on the coil in the same manner as when winding the series coil, after which the winding is completed, the terminals are soldered on and the coil is removed from the form. The veneer collars are fitted and placed in the same manner as on the series coil. Both series and shunt coils are dipped in air-drying japan and thoroughly dried before being assembled.

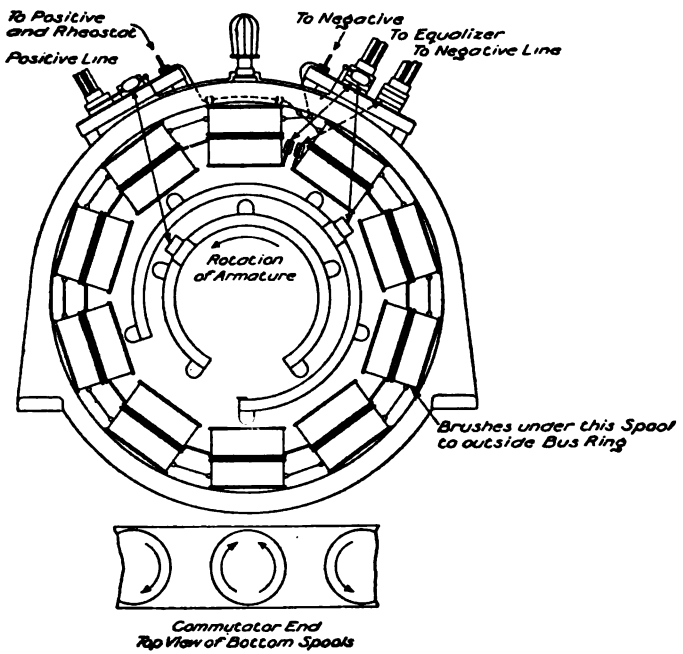


FIG. 102.—Diagram of Connections.

Compounding.

The generator is compound wound and is provided with a shunt consisting of strips of German silver, to which are attached suitable terminals, which should be connected to the series terminals on the right-hand side of the machine facing the commutator. Any degree of compounding up to 10 per cent may be obtained by changing the length of the shunt. When the machine leaves the factory the

shunt is so arranged as to give the compounding called for by the specifications.

Brushes.—Fit the brushes (Fig. 103) carefully to the commutator by passing beneath them No. 0 sandpaper held closely against the surface of the commutator. Move the paper back and forth, being very careful to see that it does not leave the surface of the commutator while in motion, since in such a case, the edges of the brushes may become slightly rounded, and the results may be made unsatisfactory. A method of sandpapering the brushes, requiring a slightly greater length of time, but one which will insure good

FIG. 103.—Brush Holder and Brush.

results, is to move the sandpaper in the direction of the rotation of the armature, and on drawing it back for the next cut, raise the brush so as to free it from the paper; then lower it, and repeat the operation until a perfect fit is obtained. If the brush requires considerable sandpapering, No. 2 sandpaper may be used first, finishing with No. 0.

Position of Brush-Holder Yoke.—The brushes should be set at no load, so that the reference mark on the pedestal is in line with the reference mark on the brush-holder yoke. With the brushes in this position, the generator will compound according to the name plate stamping. No movement of the brushes is necessary when load is thrown on or off.

Method of Adjusting Type CS Brush Holders.

Clamp the body of the holder firmly on the stud with the lower edge of the box $\frac{5}{32}$ inch from the surface of the commutator. Care should be taken to see that the lower side of the box, A and A_1 (Fig. 104), is parallel to the surface of the commutator; in other words, the distance of the point A from the commutator should be the same as that of the point A_1. The brush should then be inserted in the box and properly sandpapered and fitted to the

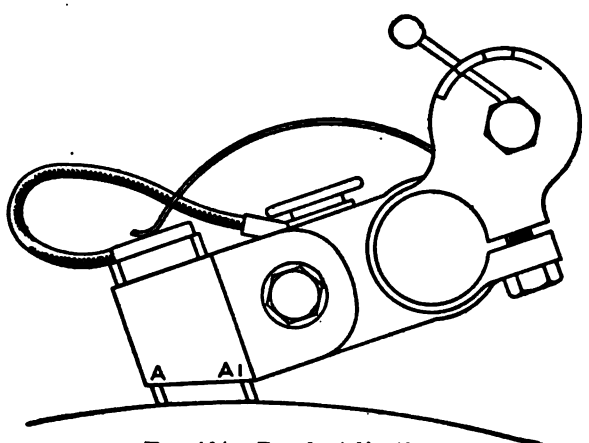


FIG. 104.—Brush Adjusting.

surface of the commutator. The pressure on the brush should be from 1½ to 2 pounds, and can be easily adjusted by placing the adjusting lever in one of the various notches.

Equalizing Rings.

A feature of the 100-kilowatt generator is the use of equalizing rings on the back of the armature. The object is to maintain the brushes of the same polarity at the same potential. Brushes of the same polarity may have differences of potential due to difference in the pole strengths at the two poles, to differences in winding, or the brushes may make unequal contact on the commutator. If two brushes are at different potentials, current will flow from one to the

other through the brushes, and the result of unbalanced current is bad sparking and excessive heating. The equalizing rings are continuous conductors secured in the back of the armature and insulated from it. Leads from the winding at the periphery connect from parts of the winding which in the different sections will be in the same position in regard to the fields. Hence, if any difference of potential exists current will equalize through these rings rather than through the brushes.

A diagrammatic sketch of these rings is shown in Fig. 105, from which the action can be understood.

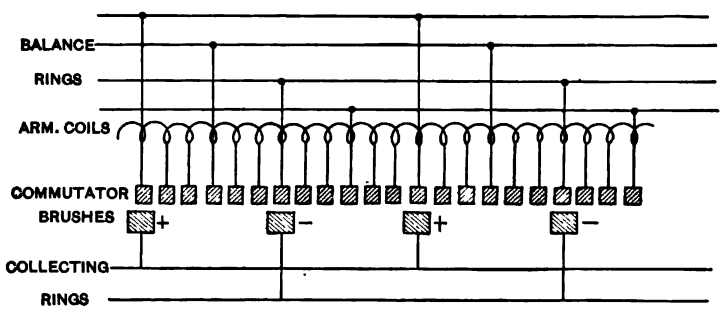


FIG. 105.—Connection of Equalizer Rings.

Specifications for 300-Kilowatt Generator Used with Turbine.

Generator.

1. To be of the direct-current, multipolar type, compound-wound long-shunt connection, designed to run at constant speed and to furnish a pressure of 125 volts at the terminals, at rated speed with load varying between no load and one-third times rated load.

2. The magnet frame will be circular in form; will have inwardly projecting pole pieces and will be divided in half horizontally, the two halves being secured with bolts to allow the upper half with its pole pieces and coils to be lifted to provide for inspection or removal of armature. The pole pieces will be bolted to the frame.

The magnet frame will be provided with two feet of ample size to insure a firm footing on the foundation.

3. Facilities for vertical adjustment of the frame will be provided.

4. The laminations for the armature will be accurately punched from

the best quality thoroughly annealed electrical sheet steel, slots to be punched in the periphery of laminations to receive armature windings. The laminations will be insulated from each other and will be assembled on the spider or shaft and securely keyed. Space blocks will be inserted between laminations at certain intervals to provide ventilating ducts for cooling the core and windings. Laminations will be set up under pressure and held securely by end flanges.

5. The commutator bars will be supported on the shell which will be keyed directly on the shaft so that no relative motion can take place between the windings and bars. The bars will be of hard drawn copper finished accurately to gauge. The insulation between bars will be of carefully selected mica or commutite of not less than .03 inch thick. The bars will line with the shaft and run true and will be securely held in place by means of clamping rings.

6. The brushes will be of carbon. Each brush will be separately removable and adjustable without interfering with any of the others. The point of contact on the commutator will not shift by the wearing away of the brush.

7. Brush holders to be staggered in order to even the wear over entire surface of commutator; the generator to be provided with some device for shifting all the holders simultaneously. All insulating washers and brushes to be damp proof and unaffected by temperature up to 100° C.

8. Finished armature to be true and balanced both electrically and mechanically, that it may run smoothly and without vibration. The shaft to be provided with suitable means to prevent oil from bearings working along to armature.

9. All copper wire to have a conductivity of not less than 98 per cent.

10. The main and commutating coils, respectively, of any one set to be identical in construction and dimensions and to be readily removable from the pole pieces. The shunt coils as well as the series coils are to be connected in series.

11. A headboard will be mounted on the generator containing the necessary terminals for main switchboard, equalizing connections, shunt and series field connections, and pilot lamp.

12. The field rheostat to be of fireproof construction suitable for mounting on back of switchboard, to be provided with handle or wheel projecting through to front, either directly connected or by sprocket chain, handle to be marked indicating direction of rotation for raising and for lowering voltage of generator. The total range of adjustment to be from 10 per cent above to 20 per cent below rated voltage, the variation to be not more than one-half volt per step at both full load and half load.

13. A metal name plate to be fitted to the generator in a conspicuous place, to be marked as follows:

MADE FOR
BUREAU OF EQUIPMENT
BY
(*Name of maker here.*)
CONTRACT No. —. REQ. No. —, 190—.
TYPE —. CLASS —. FORM —.
GENERATOR No. —.
VOLTS, —. SHUNT CURRENT, —.
AMP., —. K. W. —.

The number of the generator to be stamped on frame near name plate for reference in case name plate is shifted.

Operation of Generator.

14. The compounding to be such that with turbine working within specified limits, field rheostats and brushes in a fixed position, and starting with normal voltage at no load or at full load, if the current be varied step by step from no load to full load or from full load to no load, and back again, the difference between maximum observed voltage and minimum observed voltage shall not exceed 2½ volts.

15. The compounding and heat run (full load and overload) of the generating sets must be made with identical brush positions.

16. The dielectric strength for resistance to rupture shall be determined by a continued application of alternating E. M. F. of 1500 volts for one minute. Test for dielectric strength shall be made with the completely assembled apparatus and not with the individual parts and the voltage shall be applied between the electric circuits and surrounding conducting material.

17. With brushes in a fixed position there shall be no sparking when load is gradually increased or decreased between no load and full load; no detrimental sparking when load is varied up to one and one third times rated load, no flashing when one and one-third load is removed or applied in one stage.

18. The jump in voltage must not exceed 15 per cent when full load is suddenly thrown on and off.

19. The temperature rise of this set, after running continuously under full rated load with air of auxiliary ventilation at room temperature for four hours must not exceed the following:

	Degrees C.
Armature, by thermometer	40
Commutator, by thermometer	45
Series field coils, thermometers	40
Shunt field coils by resistance	40
Shunt rheostat, resistance method	75
Series shunt, thermometer	40

The rise in temperature to be referred to a standard room temperature of 25° C. Room temperature to be measured by a thermometer placed three feet from commutator end of the generator with its bulb in line with the center of shaft.

20. A system of air ducts for the ventilation of armature and commutator shall be provided. This system shall be connected to the ship's ventilating system. The amount of air per minute required for the various sized sets will not exceed the following:

Size of K. W.	Cubic feet air per minute.
300	3000

21. The generator to be capable of satisfactory operation for a period of two hours carrying one and one-third times its rated full load; also full load continuously in a room temperature of 35° C., without auxiliary ventilating system, and no part shall heat to such a degree as to injure the insulation.

22. Generators of the same size and manufacture to be capable of operation in parallel, the division of the load to be within 20 per cent throughout the range. The magnetic leakage at full load shall be imperceptible at a horizontal distance of 15 feet, measurements to be taken with a horizontal force instrument.

CHAPTER XV.

THEORY OF MOTORS AND MOTOR CONTROL.

An electric motor may be defined as an electric machine by which electric energy in the form of electric currents is converted into mechanical energy by the operation of conductors carrying currents revolving in a magnetic field. Machines are divided into types of constant potential, constant current and alternating current as in the case of generators, but as the system of supply on board ship is of constant potential and continuous current, only such types that come under that head will be considered and their general principles explained, together with some of the uses to which they are applicable.

General Principles.

The elementary principle of the generator was explained by the action of a straight conductor moving across a magnetic field, and in which it was shown that the power used to move the conductor was converted into electrical energy, while at the same time it overcame a force which exerted a drag on the conductor. If the conductor is supplied with a current from an external source the same drag exists on the conductor and if not overcome will cause the conductor carrying the current to move across the magnetic field. This motion will itself generate an E. M. F. in the conductor, which by Lenz's law tends to stop the motion of the conductor.

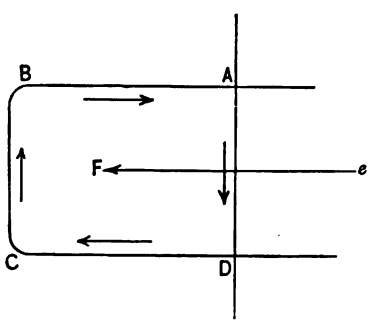


FIG. 106.—Illustrating the Principle of the Motor.

In Fig. 106, current is forced by some external means through

the straight wire AD fitted to slide along the portions AB and CD and to form portion of a closed circuit $ABCD$. The whole circuit is placed in a uniform magnetic field of intensity H, perpendicular to the plane of the paper.

A C. G. S. unit of current exists *when one centimetre of its conducting length is urged across a magnetic field of unit intensity with a force of one dyne.*

If the length of the conductor AD is l centimetres, and strength of current C absolute amperes, then the force urging the conductor across the magnetic field is

$$F = HlC \text{ dynes.}$$

The work done by this current moving the conductor at the rate of v centimetres per second is Fv ergs.

The motion of the conductor through the magnetic field induces in the conductor an E. M. F. (since E. M. F. is equal to the number of lines of force cut per second) equal to

$$E = Hlv \text{ absolute volts,}$$

and this E. M. F. opposes the flow of current in the conductor.

The work done by the current is Fv ergs, or

$$Fv = HlCv \text{ ergs;}$$

and since $E = Hlv$, the work done $= EC$ ergs per second, or

$$\text{work done} = EC \text{ watts.}$$

The work spent by the current goes to keep up the motion of the conductor.

Application to Practical Apparatus.—The general principle upon which all electric motors work is that **a conductor carrying a current will, when placed in a magnetic field, tend to move in such a direction as to embrace the greatest possible number of lines of force.**

Having seen the general principles under which generators work, we shall best understand the motor by considering it as a generator worked backwards; that is, a magnetic field is produced by an electric current, and currents are made to circulate in conductors wound on an armature, being supplied from some outside source.

The conductors carrying currents produce magnetic fields around them, and the resultant of these two fields tends to move the conductor, and if properly arranged mechanically, to produce rotation.

Figure 107 represents two conductors lying in the air spaces between two magnet pole pieces *N* and *S* and a cylindrical magnetic core. The air space is a magnetic field due to the poles *N* and *S*, the field due to these poles being represented by the straight lines running from right to left through them and the iron core, the positive direction being indicated by the arrow heads. The two conductors are marked, one *UP* representing a current flowing towards the observer as the figure is viewed, the other *DOWN*, flowing away from the observer.

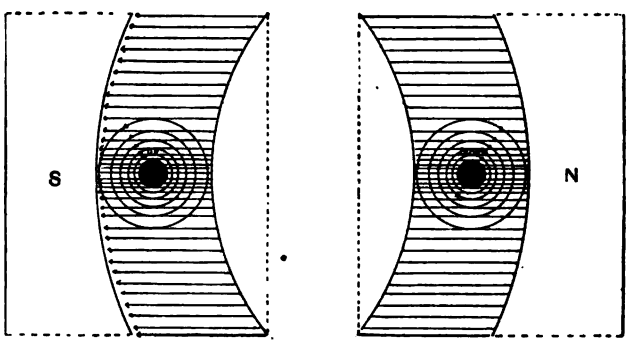


FIG. 107.—Separate Magnetic Fields.

The positive direction of the magnetic field due to the current marked *UP* is, according to the laws of induction, anti-clockwise viewed from this side and is shown as a series of concentric circles around the conductor. The field due to the current marked *DOWN* is similarly shown, the positive direction being clockwise. These two independent conductors may be considered to form part of a closed coil, the current running down on one side, through a connecting piece on the end of the core, parallel to the lines of force due to *NS* and up on the other, the two ends being connected with the source of supply of current.

If the magnetism of *N* and *S* is steady and the current through the coil is continuous and steady, the figure would represent the

effect, as far as the lines of force are considered, if there were no reaction between the fields. But there is reaction between them, the result being a compound magnetic field representing the resultant of the forces due to the poles and the forces due to the currents flowing in the conductors.

Fig. 108 shows the resultant field in the air spaces due to the magnetic field of the poles and the fields due to the current flowing in the conductor under the same conditions as stated above. The resultant field may be shown experimentally or the resultant directions of the lines of force may be proved mathematically. Remembering that the lines of force tend to shorten themselves, there being tension along them and pressure at right angles, it is clear

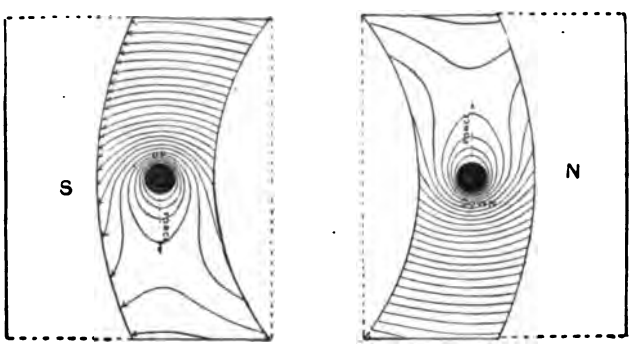


FIG. 108.—Resultant Magnetic Field.

that the pressure of the lines above the conductor marked *UP* will tend to force that conductor towards the bottom of the page as shown by the arrow, and similarly the conductor marked *DOWN* will be urged towards the top of the page.

If these conductors form part of a coil and are secured to the core which may be balanced on a shaft, the pull on one side and the push on the other side of each conductor will tend to cause revolution of the core. The tendency to revolve will be measured by the product of the force due to the current and the horizontal distance of the conductor from the center of the core. As the coil revolves, the horizontal distance between the conductor and center becomes smaller, approaching zero, which it is when the two conductors are

vertically over one another. The arm now being zero, the tendency to turn is zero, or the conductors will come to rest. In this position, the coil is now embracing the greatest number of lines due to the magnets, illustrating the principle already stated that a conductor carrying a current placed in a magnetic field will tend to move so as to embrace the greatest possible number of lines of force.

By arranging a series of coils around the core it is very evident that continuous rotation would be the result, for when one coil was in the position of zero tendency to turn, one at right angles would be in position of greatest tendency.

Torque.—It has been shown that the force developed by the current flowing in the conductor is dependent upon the intensity of the field, the current flowing, and the length of the conductor, or

$$F = HlC \text{ dynes.}$$

This force acts at right angles to the conductor and directly on it, and the total force developed is called the *drag* on the conductors. It is the force of this drag applied at the radius of the circle representing the cross-section of the core on which the conductors are wound that gives rise to the tendency to turn about a fixed axis. This tendency to turn is the twisting moment and is called the **torque.**

The torque is the product of two factors, force and distance, which produce work.

Distance or length divided by time gives velocity and work divided by time gives power.

$$\text{work} = \text{force} \times \text{distance}$$

$$\frac{\text{work}}{\text{time}} = \text{force} \times \frac{\text{distance}}{\text{time}},$$

or

$$\begin{aligned} \text{power} &= \text{force} \times \text{velocity} \\ &= \text{force} \times \text{radius} \times \frac{\text{velocity}}{\text{radius}}, \\ &= \text{torque} \times \text{angular velocity.} \end{aligned}$$

The power absorbed by a motor is, as in the case of the power developed in a generator, the product of volts and amperes;

or

$$\text{volts} \times \text{amperes} = \text{torque} \times \text{angular velocity.} \qquad (1)$$

The angular velocity is expressed in *radians* per second, a radian being the angle whose arc equals the radius, so in one revolution there are 2π radians, and the expression for angular velocity is $2\pi n$.

Substituting in equation (1), we have

$$\text{watts} = \frac{2\pi nT}{10^7}$$

where T is the torque expressed in ergs, and 1 watt $= 10^7$ ergs per second.

If T is expressed in ft.-lbs., we have

$$\text{watts} = 2\pi nT \times 1.356.$$

Since 1 H. P. $= 746$ watts

$= 550$ ft.-lbs. per second,

or 1 ft.-lb. $= 1.356$ watts.

Since $$E = \frac{nZN}{10^8} \text{ volts}$$

$$T = \frac{ZNC}{1.356 \times 10^8 \times 2\pi}. \qquad (2)$$

Expression (2) shows the important fact that the *torque is independent of the speed,* and depends only on the current flowing through the armature and on the magnetism.

Referring again to equation (1), as the torque depends on the current, the speed must depend on the volts, giving the two important facts; first, that the **torque developed by a motor depends on the current absorbed** and, second, that its **speed depends upon the E. M. F. at the terminals of the motor.**

Applied and Counter E. M. F's.

In Fig. 109 suppose there are two machines in all respects alike as to the winding of their armatures, and the fields of each are permanent, either due to permanent magnets or from current from some external source. The armature of the motor M, is directly connected to that of the generator D, and is supplied with current from it. If the armature of M is stationary, the only E. M. F. required to send a current through the conductors is that due to the resistance of the armature winding. If the torque due to this current is greater than the resistance to motion around the axis, the armature of M will turn, as explained.

The motion of the armature coils of *M* through the magnetic field induces an E. M. F. exactly similar to the case of the generator, and a consideration of the relative directions of the lines of force and of rotation will show that this E. M. F. is opposed to that of *D*. In each case, the windings of *D* and *M* are such that the induced current for the same direction of rotation tends to flow towards the upper brush, so the E. M. F. generated by *M* is opposite to that developed by *D*.

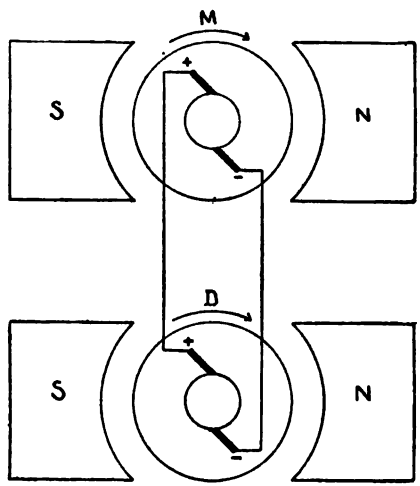


FIG. 109.—Illustrating Counter E. M. F.

The E. M. F. of the supplying generator is called the **applied E. M. F.** and the opposing E. M. F. the **counter E. M. F.** or **C. E. M. F.**

The counter E. M. F. cannot be measured directly, as a voltmeter connected to the motor terminals would show the same voltage as that of the generator terminals, less the drop in the leading wires.

In a generator, the torque is supplied by the mechanical power, being opposed to and overcoming a counter torque that is acting on the armature conductors; the overcoming of this counter torque being a measure of the power necessary to drive the armature.

Here in the motor we have the opposite effect, the E. M. F. supplied by the external source being opposed to and overcoming a counter E. M. F., and this counter E. M. F. being a measure of the power absorbed by the motor.

The counter E. M. F. being opposed to the applied E. M. F. diminishes its effect, so that the current through the armature is lessened and consequently the torque is less as the speed is increased. If the torque is still greater than the opposition to motion, the speed of the armature will increase, the current and torque decrease, until the torque exerted by the current is just equaled by the resistance to motion, of whatever nature that may be, when the speed will remain constant. So we see at the outset the important principle that **the greater the speed the less the torque to produce the same amount of power.**

When the speed becomes constant, the difference between the applied and the counter E. M. F. represents the drop through the armature, or the difference of potential required to force the current through the armature resistance. The product of this difference of potential and armature current represents the energy lost in heating the armature coils. This becomes greater as this difference increases and is a maximum when the armature is at rest, when there is no counter E. M. F., so it is seen that at this time, if the armature does not turn, all energy is lost, and a very large current would flow, so large in fact as to endanger the armature. On this account it is usual to insert in series with the armature current a resistance called a starting resistance which is made large enough to allow a small current to flow at first, producing an initial torque, and as the speed increases and counter E. M. F. increases so as to reduce the current, the starting resistance is gradually lessened, until at full speed when very little current is flowing through the armature, all the resistance is out.

Of the total E. M. F. applied to the motor, part is expended in overcoming the resistance of the armature, and is energy lost, while the difference, or the counter E. M. F. represents the energy required to keep the armature in motion, and represents the energy expended in overcoming friction losses and core losses, exactly as in the case of the generator, and in overcoming the resistance to

motion of whatever nature that may be; this latter being the mechanical work done by the motor.

To a certain extent the motor is entirely automatic as regards relation of current to external load. A certain amount of current is necessary at all speeds to furnish the torque necessary to overcome the motor losses, and if there is not sufficient current to overcome these losses, there will be no motion. Suppose the motor is running at a certain speed with a certain load, or doing a certain amount of external work, then if the load is increased, the current flowing at that time cannot furnish sufficient torque to perform this extra work, so the motor slows down. This slowing down reduces the counter E. M. F. and consequently the current increases, and the torque is now sufficient to perform the extra work the motor is called on to do. If the load is decreased, the armature has too much torque, so it speeds up, thereby increasing the counter E. M. F. and decreasing the current, and thereby the torque to the proper amount.

All that has been said regarding motors so far has reference to a field of practically constant value, in the theoretical case, the field being supplied by some constant potential source. In practical applications the field magnets of constant potential motors may be either shunt wound or series wound, or a combination of these two, corresponding to the compound-wound generator, called differential wound.

Fundamental Equation of the Motor.

The E. M. F. induced by a motor armature revolving in a magnetic field is calculated in exactly the same manner as that for a generator, and in general terms is

$$E = nZN, \tag{3}$$

where the symbols have the same signification as previously given.

Equation (3) represents the motor E. M. F. or counter E. M. F. The difference between the applied E. M. F. and the counter E. M. F. represents the drop in voltage that takes place in the armature resistance and is equal to $C_a r_a$, and, therefore,

$$\mathfrak{E} - E = C_a r_a,$$

or

$$\mathfrak{E} = nZN + C_a r_a. \tag{4}$$

Referring to the fundamental equation to the generator, the Z used in equation (4) is $\frac{pZ}{p'}$ where p and p' have the same signification as there given.

From equation (4)

$$n = \frac{\mathfrak{E} - C_a r_a}{ZN} \tag{5}$$

and

$$C_a = \frac{\mathfrak{E} - nZN}{r_a}. \tag{6}$$

Equation (6) shows that C_a cannot be calculated from Ohm's law in a running motor, and only holds when $n = 0$,

when $$C_a = \frac{\mathfrak{E}}{r_a}.$$

Under this condition, owing to the small value of r_a, C_a would be excessive, necessitating the insertion of the starting resistance in series with the armature.

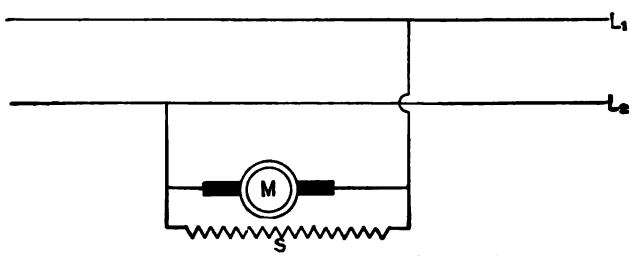


FIG. 110.—Elementary Shunt Connections.

Shunt Motors.

The elementary connections of a shunt-wound motor are shown in Fig. 110, though it must be understood that this is given for a machine that is running; the starting requiring a separate device.

In the figure, L_1 and L_2 represent the supply mains, M the motor armature, and S the shunt field.

In shunt-wound motors from a constant potential source of supply, the difference of potential at the field terminals being constant, the magnetizing force is constant and all that has been said

in reference to motors in general will apply to this case. The field being constant, the counter E. M. F. will depend on the speed, and, as has been shown, the amount of current taken varies automatically with the external load, and variations in load will make but slight changes in speed. There is no danger of a shunt-wound motor attaining such a speed as to become dangerous, for as it tends to speed up, the current and consequently the torque is decreased, and it will only attain a speed such that the torque just balances the friction or whatever the resistances to motion may be.

On account of the small variations in speed, shunt motors are used where nearly a constant speed is necessary or on moving parts that would be damaged if the speed became excessive, such as on portable fans, or ventilating sets, or pumps, and on machinery where there is not much starting and stopping, or where excessive torque is not required at starting. One disadvantage of the shunt motor is that, the field being always constant, there is always a constant loss of energy.

The previous explanation may be seen from an examination of the formulæ deduced.

When a shunt motor is running light or unloaded, the torque required to drive it is only that necessary to overcome the friction of the bearings and air friction, and is consequently small, and from equation (2) C_a must be very small. Consequently the drop through the armature $C_a r_a$ must be very small and can be neglected, since both C_a and r_a are very small, and from equation (5)

$$n = \frac{\mathfrak{E}}{ZN} \text{ at zero load.} \qquad (7)$$

As nZN is equal to E, the applied E. M. F., it is seen that at zero load, a shunt motor runs at such a speed as to make its counter E. M. F. sensibly equal to the applied E. M. F.

When load is thrown on a shunt motor, the tendency is to slow somewhat and thereby decrease nZN, the counter E. M. F. According to equation (6) C_a will then increase, as will also the torque T according to equation (2), and it is the increase of the torque which enables the motor to carry the increased load. The decrease of counter E. M. F. must be sufficient to allow enough current to flow to develop the necessary torque. If N is constant,

nZN could only vary by a drop in n, but due to demagnetizing action of the armature current, N varies, so the change in nZN is produced both by N and n, so the actual change in the speed is less than if the field was absolutely constant.

Relation Between Field and Speed.—If the field is decreased, nZN, the counter E. M. F. is decreased, and a sudden increase of armature current results, as shown by equation (6). The increased current produces more torque than is necessary to carry the load, so the motor speeds up until the increase of nZN reduces the current to the value to give the required torque.

Relation Between Brush Lead and Speed.—A generator has its maximum E. M. F. when the brushes are at zero lead, or have no lead. In the case of a shunt motor, the speed is a minimum when the brushes have zero lead, and any movement of the brushes either forwards or backwards, will increase the speed and this is particularly noticeable in a motor running light.

When the brushes are moved from the zero position, the counter E. M. F. is reduced, the speed remaining unchanged. As a result a greater current flows, producing an increased torque which causes the motor to speed up until the counter E. M. F. attains a value so as to reduce the current to the value necessary to supply the required torque.

Speed Control.—It has been shown that the speed of a shunt motor varies very little with changes of load from zero to full load, and when used for power where a varying speed is required, special arrangements are necessary.

Armature Resistance Method.—When the load on the motor is constant, its speed may be controlled by inserting resistance in series with the armature. When the resistance of the armature is large or when a large resistance is in series with the armature, equation (6) shows, that for a loaded motor, the large C_a necessary to produce the required torque can only be obtained by a large value of the numerator, $\mathfrak{E} - nZN$, and this can only be obtained by a large change in n in order that nZN can be considerably less than $\mathfrak{E}$.

On zero or light load, C_a is small, so the speed is not much affected by having r_a, or r_a + the resistance, large. This consideration shows that the change in speed for loads over a wide

range cannot be satisfactorily effected by changes in armature resistance, but for loaded motors it is effective.

Field Resistance Method.—Equation (7) shows the zero load, and consequently full load to practically the same extent, may be changed by varying N. This is effected by means of a resistance in series with the shunt winding, which can be increased or decreased, thus decreasing or increasing the field current and N proportionately.

The regulation by this means is limited, for the field cannot be increased above its saturation point, nor can it be decreased below a certain value, for the torque decreases with the field, and the magnetic reactions in the armature may overpower the weakened field.

Other methods of control applicable to motors in general will be discussed later under the head of Motor Control.

Series Motors.

With this form of motor the field varies with the strength of current. If the load on a series motor is reduced, the increase of torque, or rather the excess, causes the speed to increase, thereby diminishing the current and weakening the field, again causing the speed to increase to a greater extent to increase the counter E. M. F., than in the case of the shunt motor. If the load is increased there is a deficit of torque, the speed falls, the current increases, thereby increasing the field so that the speed must decrease considerably in order to reduce the counter E. M. F. to the proper amount. The speed, therefore, of the series motor varies considerably with the changes in load, and on this account is used on hoists, such as ash hoists, boat hoists, ammunition hoists, or where there are wanted both variations in the load and speed.

The field of the series motor may be varied in exactly the same way as the E. M. F. in a series generator is varied by cutting out some of the series turns, or introducing a resistance in parallel with the series windings.

One disadvantage of the series motor is that if by any chance all the load is thrown off, the required current is very small, and so weakens the field that it requires a very high speed to generate

the proper counter E. M. F. and the speed may become so great as to rack the armature to pieces. An advantage of this motor is that it allows a strong current and consequently strong torque at starting, a very important element in getting heavy weights such as anchors, or boats, or turrets started.

Regulation.—In certain cases, a good method of regulating these motors is to regulate the E. M. F. of the supplying generator, starting with a high E. M. F. where great torque is required, and cutting it down as the speed rises. This is not as wasteful as introducing a resistance in the main circuit, and keeping the supplying E. M. F. constant as is sometimes done.

Compound Motors.

As the object of compound generators is to produce a constant potential at all external loads, so the object of compound or differentially wound motors is to produce constant speed under all external loads. This problem is solved by building motors with a compound field consisting of the ordinary windings of the shunt motor with a few turns of series windings, so arranged that they are opposed to each other, one tending to magnetize and the other to demagnetize. The effect of this method of winding can be illustrated by taking the case of a shunt motor with a constant potential, running at a constant speed. If the load is suddenly reduced, the excess of torque causes the motor to increase in speed which will increase the counter E. M. F. and cut down the armature current. This would tend to reduce the torque, but on account of the internal resistance of the armature, all of the current is not available for this purpose so the speed will not fall to exactly what it was before. Now in the case of the compound motor, at all times there is a constant demagnetizing effect due to the series windings, and as the current is decreased, as the armature speeds up, this demagnetizing effect is lessened, or the field strengthened, so the required counter E. M. F. is obtained without any increase of speed; or, in other words, it remains constant. It is evident then there should only be enough series turns to make up for the energy lost in overcoming the motor resistances, friction and core losses.

The speed at which the compound motor runs should be the

same speed as that, if used as a generator, it would yield an E. M. F. equal to that of the supplying source. At this speed it should run so fast as to reduce the armature current to a minimum. By making the shunt field strong enough the required speed can be made as low as desired.

If the speed is to be constant, the counter E. M. F. must be constant, and as the load changes, the torque and consequently the armature current changes, so the counter E. M. F. can only be kept constant by changes in the magnetic field which is accomplished by the series turns, the field diminishing as the current increases and vice versa.

It is usual in starting differently wound motors to have an arrangement for keeping the series turns out of circuit until the motor has speeded up, for if the series and shunt windings are properly proportioned to govern exactly, there might not be any resulting magnetism, or if one overbalanced the other, the motor might start to run the wrong way.

Other Method of Compounding.—One other method of compounding has been to wind two separate circuits on the armature, one to receive the supplied current, and the other acting as a generator, inducing its own current and which is connected to the series windings. As the armature speeds up, the induced current becomes greater and tends to increase the field, so the counter E. M. F. is obtained by a lower speed. If the armature slows down, the induced current is lessened, the field magnetism is lowered, and a higher speed is necessary to produce the counter E. M. F.

Generators as Motors.

Generators designed for continuous currents may be used, in all cases, as motors with some slight changes. A **series generator** used as a motor will run in the *opposite* direction to that in which it must be driven in order to build up as a generator.

Fig. 111 shows a diagrammatical sketch of a series generator and series motor.

In Fig. 111 the left-hand figure represents a series generator, the curved arrow representing the direction of rotation of the armature, with the resulting current in the external circuit and

through the armature represented by the arrows in those parts. The arrow A represents the resultant mechanical force between the field and armature current and in the generator the counter force that the power driving the armature overcomes.

With given connections of field to the armature, the *relative* direction of current through field and armature is the same whether used as a generator or motor, and consequently there is *no* change in the mechanical force with which the field acts on the armature conductors. In the generator the power overcomes this force, but in the motor, it produces the motion, so consequently the force that has been overcome in the generator acts to produce *opposite* rotation when used as a motor.

It is immaterial which way the current flows when used as a motor, for the reversal of the supply current simply reverses both

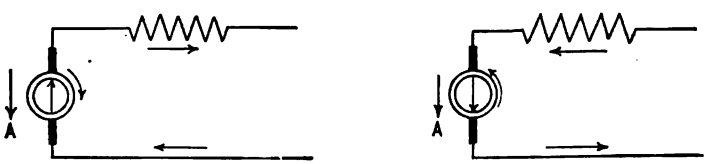


FIG. 111.—Series Generator and Motor.

the direction in the armature and in the field and does not change the relative directions, so there is no change in the force exerted by the field on the conductors.

To reverse the direction of the series motor, the armature current must be reversed without shifting the direction of the field current, by shifting the connections to the brushes.

A **shunt generator** with given connections of field to armature will run as a motor in the same direction that it must be run to build up as a generator.

Fig. 112 shows a diagrammatical sketch of a shunt generator and shunt motor.

In Fig. 112 the left-hand figure represents a shunt generator, the curved arrow representing the direction of rotation of the armature, with the resulting current in the various parts represented by straight arrows. The arrow *A* represents the resultant

mechanical force between the field and armature current and in the generator, the counter force that the power driving the armature overcomes.

In the generator, it is noticed that the current in the armature and in the field are opposed to one another, while in the motor, they are in the same direction. Consequently, in the motor, there is a *relative* change in the direction of the armature and field currents and also there is a change in the mechanical force that represents the resultant action of the field on the armature conductors. In the generator this force is overcome by the power driving the armature, and the force being reversed, now drives the armature of the motor in the *same* direction.

In this case, also, it is immaterial which way the current flows in the motor circuit for a given connection to the brushes; for the

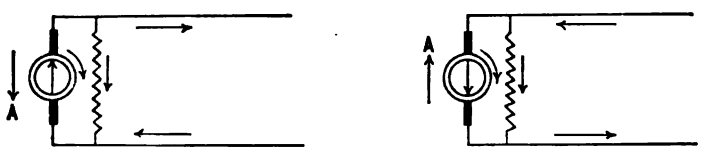


FIG. 112.—Shunt Generator and Motor.

reversal of the supply current simply reverses the current in both armature and field without producing any relative change, so there is the same change in the mechanical force, which being opposite to that of the generator, causes the motor to revolve in the same direction.

To reverse the direction of rotation of the shunt motor, either the current through the armature or through the field should be reversed, *but not both.*

Compound Generator.—A *compound-wound* generator when run as a motor will run in either direction, depending on the relative strength of the two fields.

Efficiencies of Motors.

As in the case of generators, there are three efficiencies representing the relation between the energy furnished the motor, the energy

absorbed by the motor, and the energy supplied by the motor. Of these, the first two are electrical quantities and the third mechanical, all of which must be expressed in the same units either electrical or mechanical to obtain a proper percentage of efficiency.

Gross Efficiency.—This is a term given to express the relation between the power actually absorbed by the motor and the total power supplied to the motor at the terminals. As in the notation previously used, if $\mathfrak{E}$ is the difference of potential at the motor terminals, and C, the current flowing in the supplying mains, then the total energy in watts supplied to the motor is $\mathfrak{E}C$. If E represents the counter E. M. F. and C_a the armature current, then the total power in watts absorbed by the motor is EC_a, and the gross efficiency would be $EC_a \div \mathfrak{E}C$. In the series motor $C_a = C$, and in the shunt motor $C_a = C - C_s$, the latter term representing the shunt current.

Both $\mathfrak{E}$ and C can be directly measured by connecting a voltmeter at the terminals and connecting an ammeter in series with the supply mains. The difference between $\mathfrak{E}$ and E represents the volts lost in the armature, and as in the case of a shunt generator is equal to $C_a r_a$, or $\mathfrak{E} - E = c_a r_a$. C_s is calculated by knowing the difference of potential at the shunt terminals and the resistance of the shunt, for $\mathfrak{E} = C_s r_s$. Thus knowing C and C_s, C_a is known, or it might be measured directly by connecting an ammeter in the armature circuit. Knowing C_a, the lost volts are known, which subtracted from $\mathfrak{E}$ will give E. The greater E is the greater the gross efficiency.

In the case of motors, the gross efficiency is really the efficiency of the motor *per se*, being entirely a relation of electrical quantities and corresponds to the electrical efficiency of a generator. This efficiency can be as high as it is possible to make E by reducing all core and friction losses and by making the internal resistance as small as possible.

Law of Maximum Activity.—There is a law of maximum activity which was confounded with the law of maximum efficiency in the early days when the working of motors was not as well understood as at present. The power utilized in a motor is the difference

between the total power supplied and the power lost in overcoming the internal resistances, or the heat loss, the C^2R loss.

If w is the power utilized,

$$w = \mathfrak{E}C - C^2R.$$

When w is a maximum, C has a value equal to one-half the value it would have if the motor was at rest, for

$$dw = \mathfrak{E} - 2CR,$$

which is a maximum when $dw = 0$, or

$$\mathfrak{E} = 2CR \text{ and } C = \tfrac{1}{2}\frac{\mathfrak{E}}{R}.$$

$\frac{\mathfrak{E}}{R}$ equals the current when motor is at rest, so *the maximum work is done when the motor runs at such a speed that the armature current is reduced to one-half what it would be if the motor is at rest.* This means that when the motor is doing work at its greatest activity its efficiency is only 50 per cent for

$$C = \frac{\mathfrak{E} - E}{R} = \tfrac{1}{2}\frac{\mathfrak{E}}{R},$$

or

$$2E = \mathfrak{E},$$

or, as before, the efficiency is $\frac{E}{\mathfrak{E}} = \frac{1}{2} = 50$ per cent.

Electrical Efficiency.—This is a term that represents the relation between the total power absorbed by the motor and the total power given out by the motor, the first being an electrical quantity and the second mechanical. The first term is the product of E and Ca, and it has been explained how they are obtained. The mechanical power developed at the pulley of the armature motor is the product of the torque developed and the radius through which it acts, in precisely the same way that the power exerted by the current in the armature is the product of its torque and the radius of the armature. If the torque is expressed in pounds force and the radius in feet, the work is expressed in ft.-lbs. which may be reduced to horse-power.

The torque can be measured in several ways; by finding the difference in tension of the sides of a belt that runs on the arma-

ture pulley, or by means of the Prony brake, which is simply an arrangement for measuring the friction exerted between the pulley and an arm connected to a scale which will measure the friction absorbed at any given speed. Still another method is by means of the Brackett cradle, in which the motor is mounted in a cradle and accurately balanced. When running with any load, the tendency of the field frame to turn around the armature axis by which it is balanced is measured as so many ft.-lbs., by finding how many pounds weight at a certain distance will balance this tendency, or the motor measures its own output.

Net Efficiency.—This is a term that expresses the relation between the total mechanical power produced by the motor and the total electrical power supplied, both of course being expressed in the same units. It has been explained how both of these factors are found and the net efficiency is simply the quotient obtained by dividing one by the other, and it is also numerically equal to the product of the other two efficiencies. The power supplied is called the *input* and that obtained the *output,* and the differences between these quantities represent the losses in the motor.

Motor Losses.

As stated above the total loss in a motor is represented by the difference between the input and the output and this loss is made up of the same elements as in the case of generators, part being electrical and part being mechanical losses, and made up of mechanical friction in the bearings, friction between the brushes and commutator, air friction of the revolving armature, core losses due to eddy currents and hysteresis, frame losses, due to eddy currents in the pole pieces and the copper losses in the field windings and armature conductors.

The difference between the total power supplied and the total power absorbed is represented by the heat losses in the field and armature, or is the power that is lost in overcoming the resistances of those parts. In a shunt motor, the field loss would be $C^2_s r_s$ watts and in the armature $C^2_a r_a$ watts. The total core and friction losses taken together is equal to the sum of all the losses minus the sum of the field and armature losses, and is also equal to the differ-

ence between the total power absorbed by the motor and the power developed by it.

Since the speed of a shunt motor is practically constant at all loads, the losses are practically constant at all loads, and they can be very approximately calculated by finding what current will run the motor free at its given speed. There is no output and the input represents the mechanical and core losses and the loss in the field, as the armature loss will be so small that it may be neglected.

As an example, suppose a shunt motor requires a current of 8 amperes at 80 volts when running free at 1500 revolutions. Armature resistance .04 ohm and shunt resistance 20 ohms.

Field current or $C_s = \frac{80}{20} = 4$, and $C_a = C - C_s = 8 - 4 = 4$.

Loss in field $C^2_s r_s = 4 \times 4 \times 20 = 320$ watts.

Loss in armature $C^2_a r_a = 4 \times 4 \times .04 = .64$ watts neglected.

Total input $\mathfrak{E}C = 80 \times 8 = 640$ watts.

Mechanical and core losses $= 640 - 320 = 320$ watts.

Now suppose the net efficiency was wanted when the motor was working with a current of 36 amperes.

As before $C_s = \frac{80}{20} = 4$ and $C_a = 36 - 4 = 32$.

Loss in field $C^2_s r_s = 4 \times 4 \times 20 = 320$ watts.
Loss in armature $= 32 \times 32 \times .04 = 41$ "
Mechanical and core losses (as above) $= 320$ "
Total losses $= 681$ "
This leaves $(80 \times 36) - 681 = 2199$ " as the output,
or the efficiency $= \frac{2199}{2880} = 76.4$ per cent.

As a matter of experiment this motor when absorbing 36 amperes and 80 volts, showed 2.97 H. P. at the pulley, or $2.97 \times 746 = 2214$ watts, which would give an efficiency $= \frac{2214}{2880} = 76.8$ per cent, showing that the mechanical and core losses calculated when running free must have remained constant under the increased load which was great enough to require 36 amperes.

In order to separate the total friction and core losses, that is, separate the loss due to mechanical friction, that due to eddy cur-

rents, and that due to hysteresis, it becomes necessary to make other connections and make observations at different speeds, as we saw under generators that eddy currents vary with the square of the speed, and hysteresis directly as the speed. An ordinary way of doing this is to separately excite the field magnets and to note the number of volts and amperes absorbed when the motor is running at different speeds with no load. Using the amperes as ordinates and the volts as abscissæ, curves can be plotted, the ordinates of which, being proportional to the current, will represent the losses at that current. If the curve is a straight line parallel to the axis of volts, all the losses are directly proportional to the current or there is no loss due to eddy currents, but if the curve makes an angle with the axis of volts, the increase of ordinates over those due to friction and hysteresis represent losses due to the eddy currents.

To further separate the friction losses from hysteresis loss the armature should be coupled direct to another similar machine running without a field excitation, when the increase of current necessary to run this second machine will be a measure of the frictional loss, which deduced from the other total loss independent of the eddy loss, will give the hysteresis loss.

Motor Control.

By this term is meant the operation of devices introduced between the supply lines and a motor by which the motor is stopped or started, and by which the direction and speed of the armature is controlled. The systems of control used in motors on ships of the navy are those generally known as the Automatic Rheostatic system, the Leonard system, the Day system, and the Panel system. The devices by which these systems are put in operation are generally known as Starting Panels or Controllers, which contain the necessary switches, fuses, resistances, etc., for controlling the current.

Operation of Motors.

If the armature of a motor at rest was suddenly connected to a source of supply of current, an abnormally large current would flow

through the armature owing to its low resistance. This arises from the fact that as the armature is at rest, it cannot develop any counter E. M. F. to reduce the incoming current. It does, however, do so the moment it commences to revolve and as its speed increases, counter E. M. F. is generated to sufficiently reduce the current to its normal flow.

To prevent this first sudden inrush of current, it is usual in all forms of motors that are to be used as motors alone to introduce a resistance in series with the armature, so that when the circuit is first established only sufficient current flows through the armature to produce sufficient torque to cause revolution of the armature.

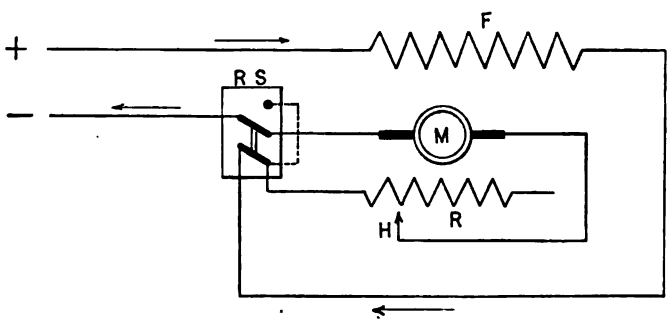


FIG. 113.—Control of Series Motor.

As soon as the armature starts to revolve and counter E. M. F. is generated, this reduces the supply current, so some of the resistance may be cut out which will allow more current to flow and greater torque to be produced. As the armature speeds up, the resistance is gradually cut out until the armature terminals are directly connected to the full voltage of the supplying mains and the armature is running at its full speed.

It has been previously shown that in order to reverse the direction of revolution of the armature that either the field current or the armature current must be reversed, *but not both.* In some cases of reversal the armature current is reversed and this might be considered the ordinary way, but in others to be mentioned later, the field current is reversed.

Rheostatic Control.

Series Motors.—This form of control is illustrated in the elementary diagram shown in Fig. 113.

To Start.—The field coil *F* is in series with the armature through the rheostat *R* and connected to the supply lines marked + and — through the reversing switch *RS*. When the switch *RS* is first closed, all the resistance *R* is in circuit, but as the armature *M* commences to turn and develop counter E. M. F. the resistance is gradually cut out until the arm *H* rests on the last contact of the resistance when the armature receives the full line voltage. This constitutes the rheostatic control for starting. In actual starting

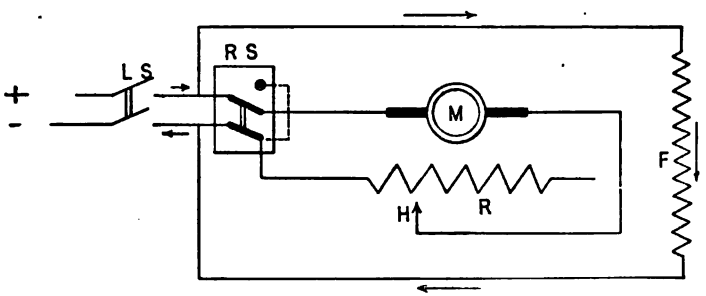


FIG. 114.—Control of Shunt Motor.

devices for series motors, the armature current and field current are connected to the mains at the same time by means of the switch or controller, after which the resistance in the field is gradually cut out.

To Stop.—To stop it is only necessary to reverse the operation of starting, moving the rheostat arm over the contact points until the last is reached when the field and armature current is broken at the same time by the switch. It is well to make the motions quickly to avoid the sparking that might occur when the circuits are broken.

To Reverse.—To reverse the direction of rotation of the armature it is only necessary to move the switch *S* to the other contact points shown, when an inspection will show that though the current through the field is in the same direction as before the direction

through the armature has been reversed. To do this, however, the armature should first be brought to rest and with all the resistance in circuit.

Shunt Motors.—The control for shunt motors is illustrated in the elementary diagram shown in Fig. 114.

In addition to the reversing switch, which in the case of series motor also acts as a starting switch, a shunt motor should be provided with a double-pole switch in the main line and the usual starting resistance.

To Start.—Close the double-pole switch *LS* which sends current through the shunt coils *F* and excites them at the constant potential of the line marked + and —, and it is important to note that in all cases the motor field is energized before any voltage is applied to the armature. The switch *RS* should then be closed one way or the other, sending current through the resistance *R* in series with the motor armature *M*. The resistance *R* is then gradually cut out as in the case of the series motor and the armature brought to speed.

To Stop.—The line switch *LS* should be opened, first cutting off the armature current, and as soon as the armature is at rest, the arm *H* should be run quickly back throwing in all resistance ready for starting again.

If the rheostat arm is moved first there is likely to be bad sparking or flashing when the off position is reached and when the line switch is opened there is apt to be a long arc endangering the field coil insulation.

Cause of Flashing.—This is caused by the self-induced current in the field as the field current commences to weaken. The induced current tends to keep up the field current and on account of the number of turns in the field winding and the iron core, the momentary current has a high E. M. F. which manifests itself when the circuit is broken by the spark, a manifestation of the tendency of the induced current to keep on flowing.

To Reverse.—When the motor is at rest, it is only necessary to shift the reversing switch *RS* to its other contacts, and it will be then seen that, as the field connections are beyond this switch, the

current through it will be as before, while the current through the armature is reversed.

Compound or Differential Motors.—These are started and stopped in exactly the same way shunt motors are, it being usually arranged that the compound windings (series) are not thrown in circuit until all the starting resistance is cut out and the motor is running at its full normal speed.

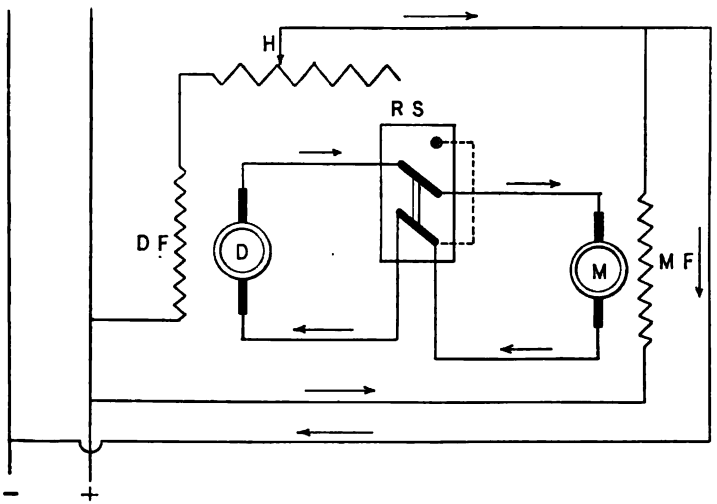


FIG. 115.—Ward Leonard System of Control.

The Leonard Control.

In the rheostatic method of control it is seen that in starting motors only a small portion of the line voltage is applied to the armature terminals at first, being gradually increased as the motor gets up its speed. It has also been shown that this is effected by means of a resistance in series with the armature, which with the armature resistance is sufficient to reduce the first current to about $1\frac{1}{2}$ times the full-load current. Thus, about half the voltage applied is used up in this resistance, being equal to the current flowing times the resistance, and is dissipated as heat. This is a great loss in economy and the object of the Leonard control is to generate only

enough voltage to produce the desired current without the intervention of the wasteful resistance.

This system of control finds its greatest application to ship's motors in turret-turning and gun-elevating motors, and will be fully described later; at this time only the elementary principles being explained.

The elementary diagram illustrating this method of control is shown in Fig. 115.

In figure, *D* is a generator armature directly connected to the motor armature *M* through the reversing switch *RS*, *DF* is the generator field, and *MF* the motor field. The supply mains + and — are energized to full potential by some other source of power.

As long as the generator field is broken by the arm *H* being off the rheostat *R*, the field of the generator is not energized and there is no voltage generated in it, though the motor field is fully excited from the mains.

When *H* first makes contact with *R* a small current then flows through the generator field and the generator armature revolving in this field generates a small difference of potential which is impressed on the motor terminals. As soon as this voltage is sufficient to generate enough current to produce the necessary torque the motor armature commences to turn, and will attain a speed proportional to the volts impressed on its terminals and which in turn is the full amount generated by the generator.

By cutting out the resistance in *R*, the voltage of *D* gradually increases, the voltage at *M* increases the same, and the motor armature gradually speeds up.

By this method of control there is no wasteful energy in motor armature resistances and the changes of speed are gradual and can be absolutely controlled by the generator field rheostat from start up to the maximum speed.

The direction of rotation of the motor armature can be changed by shifting the reversing switch *RS*.

To slow the speed it is only necessary to cut in resistance in *R* and if this is done quickly the voltage at the terminals of *D* may fall much below that of *M* for the instant, in which case *M* will

now tend to act as a generator and will generate large currents, quickly slowing it down until the voltage reaches that of *D*.

If from any cause the voltage of *D* is cut off, and the load on *M* tends to rotate it, the motor will then act as a generator short-circuited at its terminals and the large currents generated will act as a counter drag on its conductors and quickly bring it to rest.

The Day Control.

This system of control finds its greatest application in hoisting work, in which it is necessary to have the hoisting mechanism overhaul itself as quickly as possible as well as to have its speed absolutely controlled. When a weight is to be lowered, it may not exert sufficient force to overcome the friction of the moving parts, in which case it is necessary to have a motor to start it, or it may fall by its own weight, in which case it will cause the motor to act as a generator, and the braking action of the motor armature in controlling the speed in lowering constitutes the chief feature of the Day control.

For hoisting it is usual to have the resistance in series with the armature both for starting and for speed control, but for lowering a load or carrying very light loads a different combination is made, so that the rheostat to which the controlling switch is connected, instead of being in series with the armature and gradually short-circuited as the armature is brought up to speed is connected across the line in parallel with the armature.

The elementary connections are shown in Fig. 116.

By this arrangement a small amount of current is taken from the line through the rheostat *R* while the armature is being operated, in addition to the current taken or given out by the armature itself, according as it is acting as a motor or as a generator.

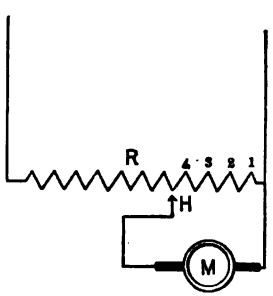


FIG. 116.—Day System of Control.

On the first contact of the resistance, the rheostat is connected across the line and the armature is in parallel with a very small portion of the rheostat.

The portion of the rheostat between the armature terminals may be considered as being in parallel with the armature as far as current taken from the line is concerned, and in series with the armature as regards current produced by the armature itself.

If on lowering, and on the first contact of the resistance, the load does not start, the motor armature will receive a small current from the line through the rheostat and proportional to the difference of potential between the points on the resistance to which it is connected. If the armature does not now start, throw in more resistance in parallel with the armature, shown in Fig. 116, by moving *H* more to the left. This will allow more current to pass through the rheostat into the armature, or the difference of potential between the terminals will now be greater.

If, however, in the first instance, the load was sufficient to overhaul itself, it would cause the motor to act as a generator and current would be given out by the armature through the small portion of the resistance with which it is now considered as being in series. The load still overhauling, any further movement of *H* to the left would cause the motor to move faster, as it is now generating current through an increasing resistance. To slow in this case, it is only necessary to move the contact arm to the right, when the motor is generating current through a smaller resistance, when larger currents would flow, and as this energy is brought into existence by the falling load it would gradually slow down, until when the armature circuit is short-circuited, the powerful currents induced would act as a counter torque and bring the weight to rest.

Moving the contact arm to the left, the armature will be gradually brought to full speed, whether the motor is acting as a generator as has been shown, or whether it is taking current from the line.

In this way the speed can be controlled no matter whether the motor is really lowering the load or whether the load is driving the motor.

In the ordinary rheostatic control with the resistance in series with the armature, more resistance turned into the circuit will cause the armature to run faster when it is driven by its load and there is no way of reducing its speed below its full-load speed.

Panel Control.

The systems of control previously discussed have had to do with the different means of starting motors by means of variable resistances in series or in parallel with the main current, and the variation in speed caused by changes in the voltage impressed on the motor terminals by changes in this resistance.

In the Panel control, the usual starting resistance is used, but changes in speed are caused by changes in the field excitation.

Speed Regulation by Change of Field Excitation.

Suppose a motor with constant voltage applied to its terminals to run with a constant load. The motor will run at constant speed, the current being just sufficient to overcome all losses and the resistance due to its load. If the field current is lessened, the counter E. M. F. would decrease in the same proportion if the speed remained as before. This would allow a greater current to flow through the armature and the increased power due to the increased current would cause the motor to run faster, until the counter E. M. F. had increased to such a value that the power absorbed by the motor was sufficient to overcome the resistance of the load at the new speed.

This shows a *decrease in the field excitation, produces an increase in the speed,* and vice versa.

The regulation of speed in a shunt motor is easily attained by connecting a variable resistance in series with the shunt winding, and as the current is small, the waste of power, or heat loss, is not great. In many cases variation in speed is attained by putting resistance in series with the armature.

In a series motor, the field regulation is more economically carried out by connecting a variable resistance in a branch circuit in parallel with the series winding. The current round the series coils is then decreased by decreasing the variable resistance in the branch circuit, causing more current to pass through this branch resistance instead of around the series windings.

Problems on Motors.

1. A shunt motor has an armature resistance of .04 ohm and a shunt resistance of 20 ohms. A current of 36 amperes is supplied at an E. M. F. of 80 volts; the armature makes 1500 revs. a minute, giving a tangential pull of 44 lbs. at the surface of a pulley whose circumference is 18″. Find the loss by heat in the armature and field, the counter E. M. F., the current in the armature and shunt, and the efficiency (net).

$\mathfrak{E} = C_s r_s \qquad C_s = \frac{80}{20} = 4 \qquad C_a = 36 - 4 = 32,$

$\mathfrak{E} = E + C_a r_a \qquad$ or $E = 80 - (32 \times .04) = 78.72.$

Watts lost in field $= \mathfrak{E} C_s = 80 \times 4 = 320$

Watts lost in arm. $= C_a^2 r_a = \overline{32^2} \times .04 = 40.96$

Total loss $= \overline{360.96}$ watts.

Watts supplied $= \mathfrak{E} C = 80 \times 36 = 2880$ watts,

Watts developed $= E C_a = 78.72 \times 32 = 2519.04$ "

or loss $= \overline{360.96}$ "

H. P. avail. $= \frac{1500 \times 3 \times 44}{2 \times 33000} = 3$ or $3 \times 746 = 2238$ watts.

Net eff. $= \frac{2238}{2880} = 77.7\%.$

2. In a shunt motor, resistance of field coils 50 ohms, of armature .2 ohm, total current entering 25 amperes, difference of potential 100 volts, H. P. as indicated by dynamometer 2.75, find the electrical, gross, and mechanical efficiencies.

Ans. Gross eff. $= 87.7\%.$
Elec. eff. $= 93.5\%.$
Mechanical eff. $= 82\%.$

3. A shunt motor has a field resistance of 33⅓ ohms, and an armature resistance of .06 ohm. The difference of potential is 100 volts and the current 48 amperes. The radius of the pulley is 3″. The difference of the weights of a flexible band dynamometer is 63 lbs. and the number of revolutions is 1800 per minute. Required, the gross, electrical and commercial efficiencies, and the loss in heating the coils.

$C_s = \frac{\mathfrak{E}}{r} = \frac{100}{33\frac{1}{3}} = 3$ amperes,

$C_a = 48 - 3 = 45 \qquad \mathfrak{E} - E = C_a r_a,$

or $E = 100 - 45 \times .06 = 97.3.$

Watts supplied $= \mathfrak{E} C = 100 \times 48 = 4800,$

Watts utilized $= E C_a = 97.3 \times 45 = 4378.5$

Watts lost in heating $\overline{421.5}.$

Total output $= \omega T$ where ω is the angular velocity and T the torque in ft.-lbs. $\omega = 2\pi n.$

ωT in ft.-lbs. $= 2\pi n T \times 1.356$ in watts,

for 1 H. P. $=746$ watts and 1 ft.-lb. per sec. $=\frac{33000}{60}=550$ ft.-lbs.

or 1 ft.-lb. per sec. $=\frac{746}{550}=1.356$ watts.

$\therefore$ output in watts $=2\times\frac{22}{7}\times\frac{1800}{60}\times 63\times\frac{1}{4}\times 1.356=4027.4.$

Gross eff. $=\frac{4378.5}{4800}=91.22\%.$ Elec. eff. $=\frac{4027.3}{4378.5}=92\%.$

Commercial eff. $=\frac{4027.3}{4800}=83.9\%.$

4. An electric motor, shunt, has an armature resistance of .055 ohm and field resistance of 32 ohms. When making 1400 revs. per minute the tangential pull on a pulley 7.6 cm. radius is 25 kilos. The current supplied to the motor at a voltage of 105 is 35 amperes. Calculate the counter E. M. F., the heating effect, and the gross and mechanical efficiencies.

Output $=\frac{2\pi nT}{10^7}$ watts, where T is the torque expressed in ergs, 1 watt being equal to 10^7 ergs per sec., or output in watts

$$=2\times\frac{22}{7}\times\frac{1400}{60}\times\frac{7.6\times 25\times 1000\times 981}{10^7}=2733.7$$

$7.6\times 25000=$ gr. cm. which multiplied by 981 gives ergs.

$C_a=\frac{\mathfrak{E}-E}{r_a}$ or $E=\mathfrak{E}-C_a r_a=105-31.72\times .055=103.255,$

$\mathfrak{E}=C_s r_s \qquad C_s=\frac{105}{32}=3.28 \qquad C_a=35-3.28=31.72,$

$\mathfrak{E}C_a=105\times 35=3675$ watts,

$EC_a=103.26\times 31.72=3275$ "

Heating effect $\overline{400}$ "

Gross eff. $=\frac{3275}{3675}=89.125\%.$ Mechanical eff. $=\frac{2733.7}{3675}=74.38\%.$

5. A Thompson-Houston motor has an armature resistance of .06 ohm and field resistance of 33⅓ ohms. While absorbing a current of 32 amperes at 102 volts, the armature made 1350 revs. per minute with a tangential pull of 60 lbs. on a pulley 6 inches in diameter. Calculate the heating effect and the mechanical energy delivered and the electrical energy supplied.

Ans. Heating effect = 362.36 watts.
Elec. energy supplied = 3264.00 "
Mech. energy delivered = 2876.6 "

6. A shunt motor connected to 110-volt mains, when unloaded, takes 3 amperes in the armature and runs at a speed of 997 revs. per minute. The armature resistance is .11 ohm. Calculate the resistance that must be connected in series with the armature to reduce its speed to 800 revs. per minute when the armature current is 50 amperes. *Ans.* .33 ohm.

7. In the preceding example, the shunt current was 2.6 amperes and at full load, 50 amperes, the actual speed was 980 revs. per minute. This machine is now driven as a generator at a speed of 980 revs. per minute and the field rheostat is adjusted to give the same field current as before. Find the terminal voltage of the generator when the armature current is 50 amperes, and the difference in the resistance of the field (field and rheostat) in the two cases when acting as a generator and as a motor.

If the field current remains the same and the speed as a motor and generator constant, the counter E. M. F. of the motor will be equal to the total E. M. F. as a generator.

Counter E. M. F. $= 110 - C_a r_a = 110 - 50 \times .11 = 104.5$

e as generator $= E - C_a r_a = 104.5 \times 50 \times .11 = 99$ volts.

Resistance of field and rheostat as motor $= \frac{110}{2.6} = 42.3$ ohms.

Resistance of field and rheostat as generator $= \frac{99}{2.6} = 38.1$ ohms.

8. A 110-volt shunt motor has a speed of 1200 revs. per minute. The resistance of the shunt field is 110 ohms. The constant stray loss due to friction, eddy currents, etc., is 250 watts. The armature resistance is .4 ohm. Find the value of the armature current for which the efficiency is a maximum and find this maximum efficiency.

NOTE.—The maximum efficiency occurs when the variable loss is equal to the constant loss. *Ans.* 30 amperes.
78.9%.

9. Assuming that the armature flux of example 6 is constant at all loads, find the value of the counter E. M. F. and speed for which the output is a maximum; the value of the output and the efficiency. The shunt current is 2.6 amperes.

NOTE.—Maximum output results when the motor has such a speed that the current is reduced to half what it would be if at rest.

At rest $C_a = \frac{110}{.11} = 1000$ amperes,

for maximum output $C_a = \frac{1000}{2} = 500$ amperes,

$\mathcal{E} - E = C_a r_a$, or $E = 110 - 500 \times .11 = 55$ volts,

$$E = \frac{nZN}{10^8} \qquad 110 - 3 \times .11 = \frac{997NZ}{10^8}$$

$$\frac{NZ}{10^8} = \frac{109.67}{997} = .11,$$

$$110 - 50 \times .11 = \frac{nNZ}{10^8} = n \times .11, \quad \text{or } n = \frac{55}{.11} = 500 \text{ R. P. M.}$$

Total input $= 110 \times 502.6 = 55286$ watts.

When unloaded, power absorbed $= C_a E = 3 \times 109.67 = 329$ watts, or 329 watts are expended without doing work.

Total output $= C_a E - 329 = 500 \times 55 - 329 = 27.171$ watts.

$$\text{Eff.} = \frac{27.171}{55.286} = 49.2\%.$$

10. A motor generator is built up of a motor and generator mounted on a common shaft. Characteristics of motor: drum wound armature with 65 complete coils, armature flux 8,000,000 lines; difference of potential at terminals 110 volts; resistance of armature .1 ohm, of shunt winding 44 ohms, external current 62.5 amperes. Characteristics of generator: long shunt compound wound; ring armature with 120 coils; armature flux 9,200,000 lines; resistance of armature .09 ohm, of series winding .11 ohm, of shunt winding 50 ohms; total external resistance 2 ohms. Calculate the current the generator will deliver.

Ans. 50 amperes.

CHAPTER XVI.

SERVICE MOTORS.

At the present time nearly all the power used on board naval vessels, with the exception of the power for propulsion, for capstans and steering engines, is furnished by electric currents through the medium of electric motors. Electric power is used for turret training, gun elevating, ammunition hoists of all kinds, boat hoists, deck winches, coal hoists, ash hoists, air compressors, water-tight doors and hatches, work shop machines, ventilating fans, blowers, and miscellaneous uses, such as operating laundry machines, printing presses, meat choppers, dough mixers, ice-cream freezers, potato peelers, etc.

Motors for operating the various machines and devices are located at different parts of the ship, all subject to different conditions of wear and use, some on deck where they are liable to be drenched with salt water and exposed to rain, as boat hoists and winches, besides exposure to coal dust when coaling; some subject to flying spray at times, as the turret motors and gun-mechanism motors. Others are located in the lower parts of the ship subject to great heat and in out of the way places, where they can get little care, as ventilating fans in air ducts and trunks. Some are in the fire-rooms, as the forced draft blowers, subject at all times to great heat and flying coal dust.

Some motors are constantly used, as the ventilating fans, some not so often as fans for forced draft, and others intermittently as boat, and other hoists and deck winches. Some run continuously, as fans, without change of speed or load, others, as turret motors, are continually starting, stopping, reversing, and changing in speed and load. Each class of motor then must be designed for the particular work that it is required to do and only a few requirements are applicable to all. It is very evident that they should be of inclosed water-tight and dust-tight type, of particularly strong

mechanical construction so as to be able to stand hard usage, and strong electrically to stand for a short time any dangerous overloading. As far as possible all should have automatic or self-oiling bearings and the brushes should be fixed and fitted so as not to jump away from the commutator, and should be independent of care and attention. The motors should be of such good mechanical and electrical construction that the only care necessary should be an occasional trimming of the brushes and a look at the commutator, and the precaution taken of seeing the oil cups filled. The starting, stopping, and reversing gear should be of the simplest description so that any one could be entrusted to run the motor.

General Specifications for all Motors.

Motors installed on board vessels of the navy are furnished under different specifications, but all conform to general requirements, and as a general guide to their construction, the specifications required by the Bureau of Construction and Repair are quoted:

1. Motors to be wound for 120 volts, direct current, for both armature and field windings, unless otherwise specified, and to be either series, shunt, or compound wound, according to work they are to perform.

2. In sizes above 4 horsepower, motors to be multipolar; 4 horsepower or below may be bipolar. Motors are to be as compact and light as possible, consistent with strength and efficiency. The method of running wires to motors to be in all cases by tapping conduit directly into the motor frames or into connection boxes attached to frames, as may be specified in each individual case; connection boxes for inclosed motors to be water-tight.

Inclosed motors should be provided with openings of sufficient size and number to give easy access to brush rigging, commutator, and field coils; such openings to be provided with covers and fastenings of approved design. The contact surfaces between these covers and motor frame should be flat machined surfaces, provided with rubber gaskets. Rubber gaskets for all water-tight work to be in accordance with the Navy standard specifications for the same as issued by the Bureau of Supplies and Accounts. All inclosed motors to be provided with drain plugs or cocks which will thoroughly drain out any water that may enter the motor casing.

3. The armature shaft to be of steel and strong enough to resist appreciable bending under any condition of overload, to have sufficient bearing surface, and to be efficiently lubricated by grease or self-oiling

bearings, as occasion may require. Bearings are to be provided with bronze or split babbitted bearing linings. Oil rings are to be turned true and free from all defects; split oil rings are not to be used. A satisfactory arrangement to be made to prevent oil from running along the shaft or being spilled. Visual oil gauges to be provided for determining the amount of oil in pocket and drains for drawing oil prior to renewal, and in addition an overflow outlet attached directly to the bearing, at such a height that it will prevent oil entering the motor frame to be supplied.

4. A name plate bearing the following data is to be attached to the motor frame: Name of manufacturer; shop number; type and class; date of manufacture; the winding, voltage, amperes, horsepower output, and revolutions per minute at rated load; the Bureau by which ordered, requisition number, and date of acceptance; also space to be provided for stamping the name of the vessel on which the motor is used.

Armatures and Field Coils.

5. All the field poles to be equally energized. In compound motors, series and shunt windings to be separate and so arranged that either winding may be removed without disturbing the other. The windings of armature and field to be well protected from mechanical injury and to be painted with water-excluding material not soluble in oil or grease. No insulating substances to be used that can be injured by a temperature of 100° C.

The armature to be of the ironclad type, built up of thin laminated disks of soft iron or steel of the very best quality, having the spaces between the teeth punched out of each separate disk and not milled after assembly.

The disks to be properly insulated from each other. The coils to be preferably of the removable type and to be retained in slots of the armature body by maple wedges running full length of armature, or other approved method. Band wires must be of nonmagnetic material in wake of pole pieces. The armature to be electrically and mechanically balanced. The windings at pulley end to be protected from oil in an approved manner. The commutator segments to be of pure hard-drawn copper. The segments to be of ample depth and insulated from each other and the shell by pure mica of such quality as to secure even wear with the copper.

Brush Rigging.

6. Brushes to be of carbon; current density in brushes must always be given and should be in accordance with the best practice. Special attention must be given to the selection of brushes, that their material may be homogeneous and the quality such as to give perfect commutation without cutting, scratching, or smearing the commutator. Brush

holders to be readily accessible for adjustment and renewal of brushes and springs; to be entirely of noncorrosive metal and of the sliding shunt-socket type, in which the brush slides in the holder and is provided with a flexible connection between brush and holder. The springs are to be phosphor-bronze and shall not be depended on to carry current. Brush holders on all motors to be adjustable for tension, and on motors of 5 horsepower and above to be adjustable for tension *without* tools, and so constructed as to permit of proper staggering of brushes. Brush holders for nonreversible motors of 5 horsepower and above to be simultaneously adjustable for position. Proper position of rocker arm to be plainly marked. This position for reversible motors to give same speed in either direction.

FIG. 117.—CB-15 Motor. Gen. Elec. Co.

Types of Motors.

Several types of motors are shown in the following cuts and have been chosen to illustrate typical forms and a knowledge of their construction and of the various parts that go to make a completed machine may be gained by a study of the figures showing the exploded views.

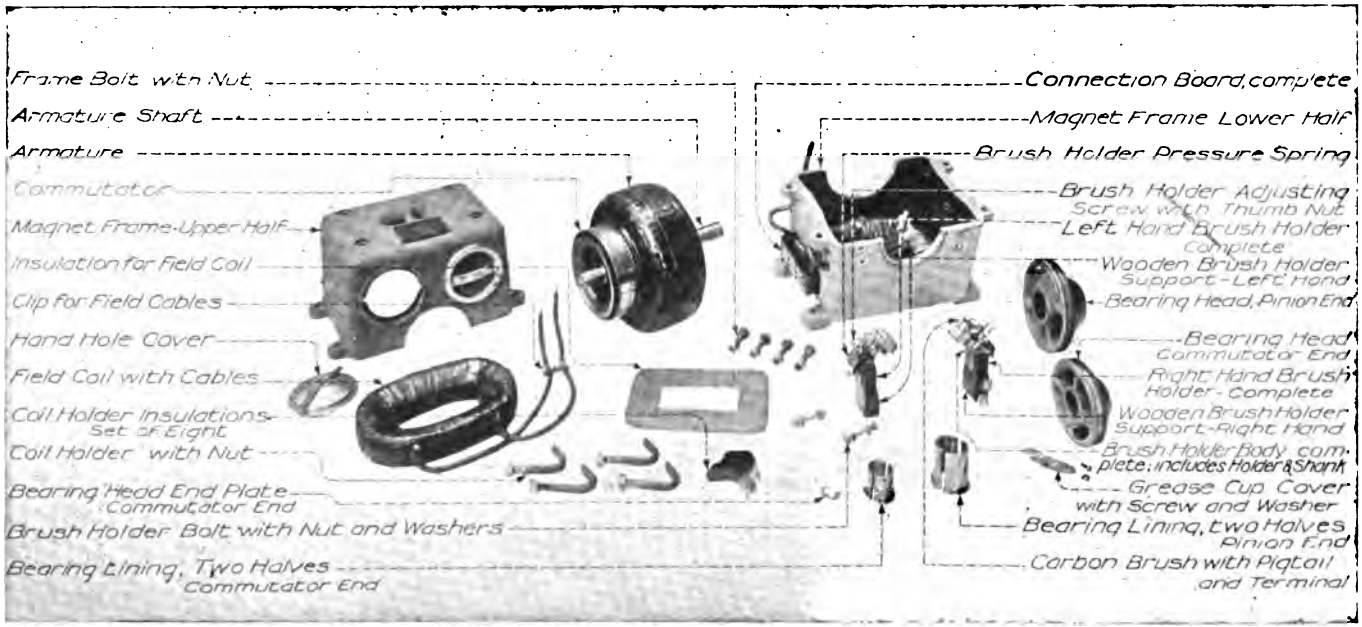

Frame Bolt with Nut
Armature Shaft
Armature
Commutator
Magnet Frame-Upper Half
Insulation for Field Coil
Clip for Field Cables
Hand Hole Cover
Field Coil with Cables
Coil Holder Insulations Set of Eight
Coil Holder with Nut
Bearing Head End Plate Commutator End
Brush Holder Bolt with Nut and Washers
Bearing Lining, Two Halves Commutator End
Connection Board, complete
Magnet Frame Lower Half
Brush Holder Pressure Spring
Brush Holder Adjusting Screw with Thumb Nut
Left Hand Brush Holder Complete
Wooden Brush Holder Support-Left Hand
Bearing Head, Pinion End
Bearing Head Commutator End
Right Hand Brush Holder-Complete
Wooden Brush Holder Support-Right Hand
Brush Holder Body, complete; includes Holder & Shank
Grease Cup Cover with Screw and Washer
Bearing Lining, two Halves Pinion End
Carbon Brush with Pigtail and Terminal

Fig. 118.—CB-15 Motor. Exploded View.

The motors are made by the General Electric Company to conform to specifications, either present or past.

Figs. 117 and 118 show respectively an assembled view and an

FIG. 119.—CB-25 Motor. Gen. Elec. Co.

exploded view of motor known as CB-15, used in some instances for 12-inch elevating motors and whip-hoist motors.

Figs. 119 and 120 show an assembled view and an exploded of motor CB-25, a series motor, used principally for boat cranes.

A longitudinal section of a CB-25 motor is shown in Fig. 121.

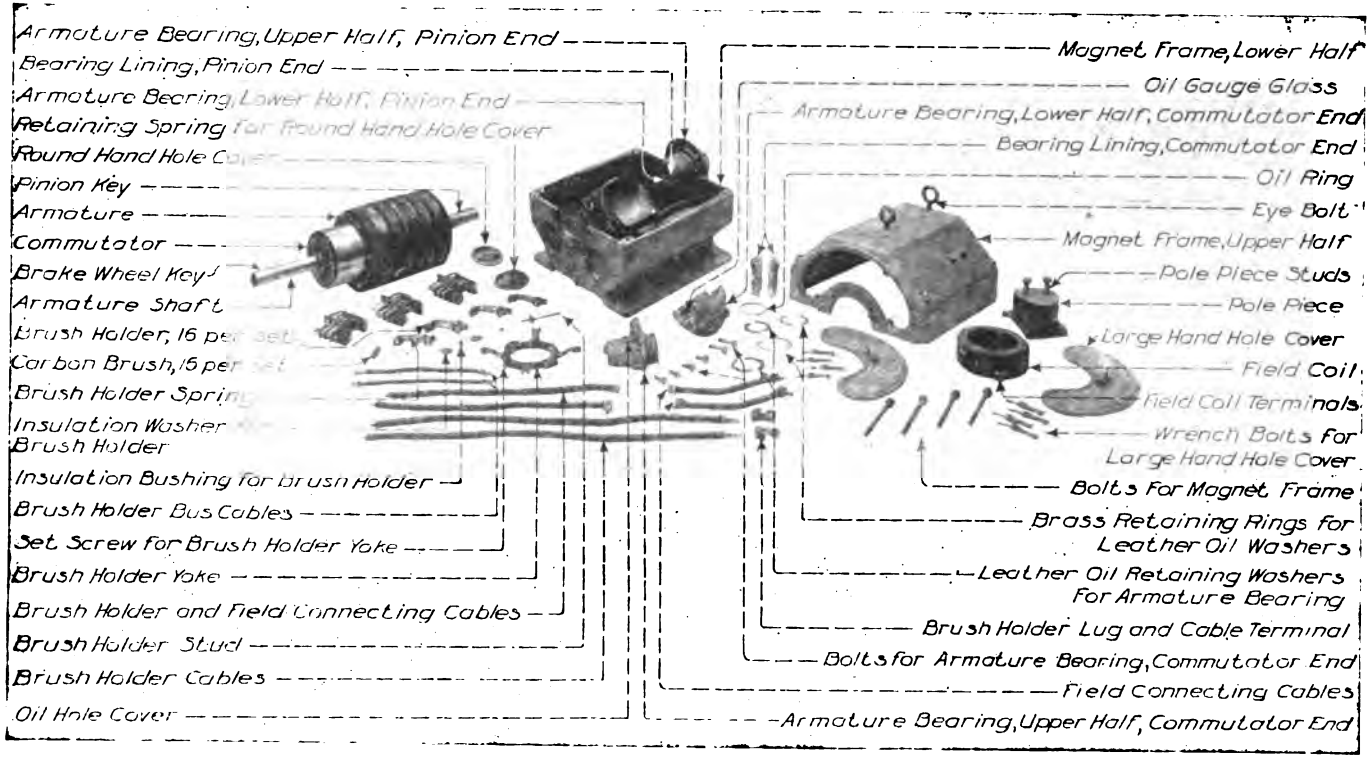

Armature Bearing, Upper Half, Pinion End
Bearing Lining, Pinion End
Armature Bearing, Lower Half, Pinion End
Retaining Spring for Round Hand Hole Cover
Round Hand Hole Cover
Pinion Key
Armature
Commutator
Brake Wheel Key
Armature Shaft
Brush Holder, 16 per set
Carbon Brush, 16 per set
Brush Holder Spring
Insulation Washer
Brush Holder
Insulation Bushing for Brush Holder
Brush Holder Bus Cables
Set Screw for Brush Holder Yoke
Brush Holder Yoke
Brush Holder and Field Connecting Cables
Brush Holder Stud
Brush Holder Cables
Oil Hole Cover
Magnet Frame, Lower Half
Oil Gauge Glass
Armature Bearing, Lower Half, Commutator End
Bearing Lining, Commutator End
Oil Ring
Eye Bolt
Magnet Frame, Upper Half
Pole Piece Studs
Pole Piece
Large Hand Hole Cover
Field Coil
Field Coil Terminals
Wrench Bolts for Large Hand Hole Cover
Bolts For Magnet Frame
Brass Retaining Rings for Leather Oil Washers
Leather Oil Retaining Washers For Armature Bearing
Brush Holder Lug and Cable Terminal
Bolts for Armature Bearing, Commutator End
Field Connecting Cables
Armature Bearing, Upper Half, Commutator End

FIG. 120.—CB-25 Motor. Exploded View.

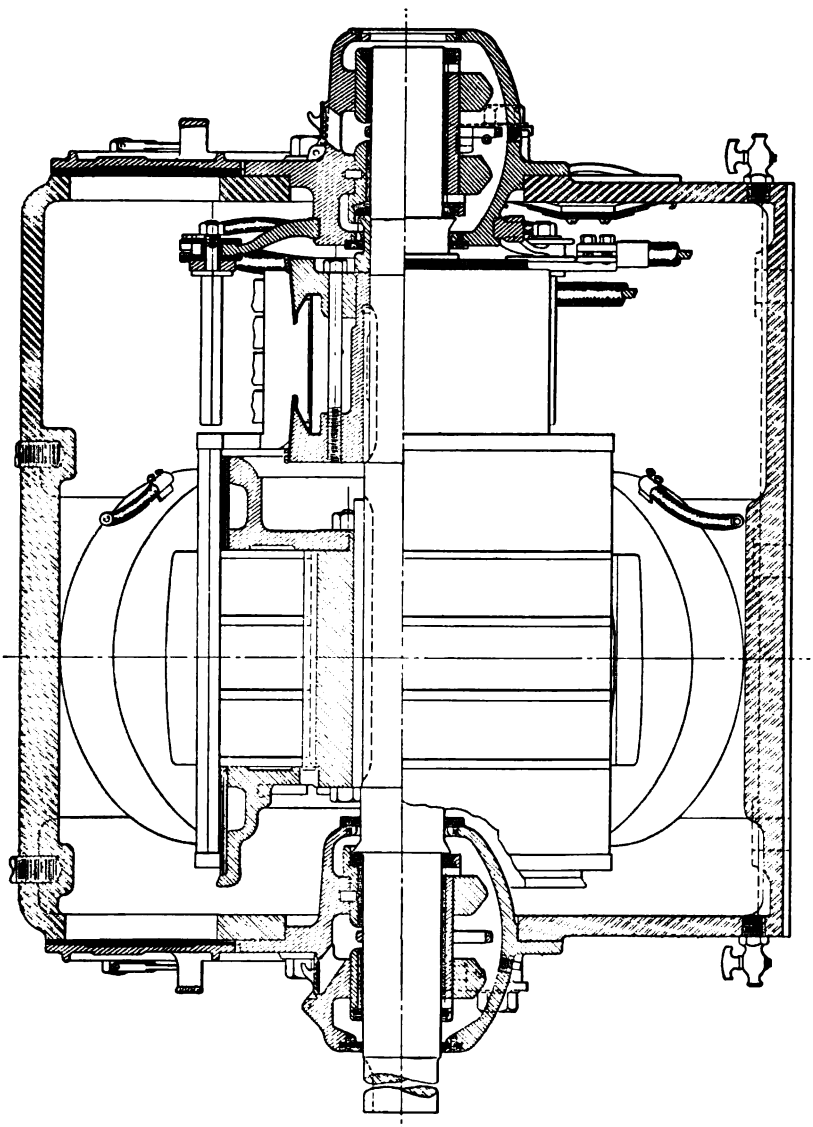


FIG. 121.—Longitudinal Section of Type CB-25 Motor.

Electrical Construction.

The winding of the armature and fields of motors is determined by the voltage to be impressed on the motor terminals, and different classes and types of motors vary in the style of winding adopted, in the number and arrangement of poles and in the number, winding, and size of conductors. As examples of the electrical construction of different types of motors used in ship installation, a description is given of motors used for chain ammunition hoists, turret turning, and boat-crane revolving.

Chain Ammunition-Hoist Motor.

Motor.—This is *shunt wound,* designed for 400 revolutions per minute at 125 volts.

Magnet Frame.—The magnet frame consists of a cast-steel shell separable in a horizontal plane through the axis, with bored seats for the pole pieces and feet for fastening the motor to its support. Hand holes are furnished with suitable covers to give access to the commutator and brushes.

Pole Pieces.—There are four pole pieces, two cast with the upper and two with the lower half of the magnet frame, and are provided with laminated steel pole tips secured in place by bolts passing through the pole pieces with nuts on the outside of the magnet frame in cored pockets.

Armature Bearings.—The armature bearings are carried in bored seats in the ends of the magnet frame which fit accurately, thus insuring perfect alignment at all times. Each is held in position by four hexagonal head cap screws, two in each half of the frame. The bearing at the commutator end contains the cone brake.

Each bearing is of the self-oiling type, carrying a large oil reservoir below the shaft, one oil ring furnishing ample lubrication. Each bearing is provided with a slot in the top which allows the insertion and inspection of the oil rings and filling the oil well. Sight oil gauges are cast with the bearings and means are provided for drawing the oil from the reservoir.

Linings.—These are of bronze in one piece, fitting accurately bored seats in the bearing and held from turning by set screws.

Field Coils.—The four field coils, each fitting around and held in place by its pole piece, are insulated with varnished cambric and tape, and then treated with several coats of insulating baking japan to give them a high insulating quality and at the same time to make them thoroughly water-proof. The ends of the windings are soldered to connectors.

Armature.—The armature is of the *drum-wound* type. The core consists of soft steel laminations securely keyed to the shaft and held in position by cast iron end discs, the core being slotted to retain the armature coils. The coils are form wound and securely held in slots of the armature core.

Commutator.—The commutator consists of a malleable iron shell supporting segments of hard drawn copper carefully insulated with mica. The commutator is securely keyed to the shaft. The ends of the armature coils are soldered into the commutator segments.

Brush Rigging.—The brush rigging consists of specially-treated insulating blocks, supported from the frame and carrying two radial carbon brushes held against the commutator by adjustable springs.

Cables and Connections.—The armature and field cables are brought through rubber gaskets at the commutator end of the frame, insuring accessibility and water-tightness.

Non-Corrosive Parts.—All screws, nuts, etc., which are liable to become corroded and broken in removal are made of non-corrosive metal, not of iron or steel. Flat springs are of phosphor bronze and spiral springs of steel, copper plated.

Test.—The motor should deliver 3 horsepower at the armature shaft when running 400 revolutions per minute at 125 volts, for a continuous period of two hours, the temperature of the various parts above the air at the end of this time should not exceed the following:

Armature winding	45° C.	by thermometer.
Field windings	50° C.	" resistance.
Commutator	50° C.	" thermometer.
Bearings	45° C.	" "

The motor should stand an overload of 50 per cent for five minutes without injury.

All windings should withstand a high potential test of 1500 volts alternating for one minute.

Efficiencies. The efficiency of this motor at the armature shaft should be as follows:

¼ load	60.5	per cent.
½ "	74.5	" "
¾ "	77.5	" "
Full load	79.0	" "

FIG. 122.—CB-27 Form B Motor. Gen. Elec. Co.

Brake.—There is an electric cone brake forming a part of the commutator end bearing. This is so arranged that the braking friction is released when the operating coil is excited and set when the current fails. This coil is entirely protected from mechanical injury and is so designed that it can be replaced in case of damage.

Panel.—The motor is controlled by the type known as U. S. Panel.

Fig. 122 shows an assembled view of motor known as CB-27, used on chain ammunition hoists, while Fig. 123 shows a longitudinal section of the same motor.

A Turret-Turning Motor.

Classification.—This motor is of the **armored type, shunt wound,** and classified as CB-24-A2-35 H. P.-354 R. P. M.-80 V.

NOTE.—**The first three figures and letters indicate the manufacturers shop number; type and class. 35 H. P. means that at its rated speed the output of the motor is 35 horsepower; 354 R. P. M. means that at its rated load, the armature shaft will make 354 revolutions per minute; 80 V means that the E. M. F. to be impressed on the terminals to produce the rated horsepower and speed is 80 volts.**

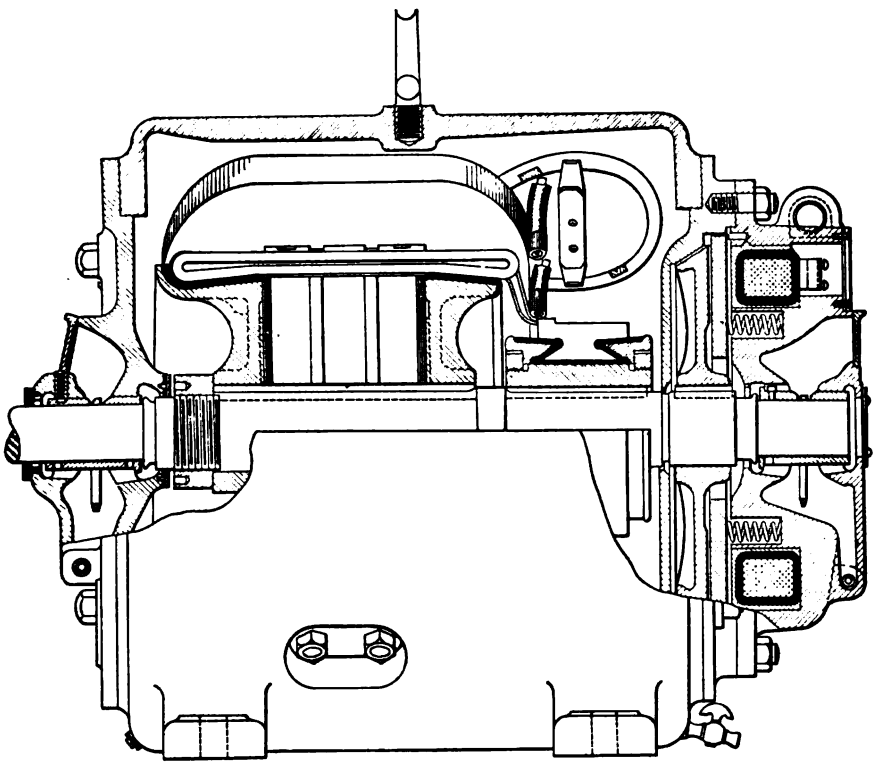


FIG. 123.—**Assembly of CB-27 Motor with EC-104 Brake.**

Magnet Frame.—The frame is cast steel, octagonal in shape, and separable in a horizontal plane to allow of easy access to the armature and field windings. The frame is entirely enclosed, this being

a characteristic of the armored type, but access to the brushes, commutator, and connections is afforded by four oval-shaped openings at each end of the frame and three rectangular-shaped openings in the upper frame at the commutator end. These openings are provided with water-tight covers held in place by clamping bolts.

Pole Pieces.—The pole pieces are four in number, made of cast steel, held in place by one bolt and so shaped as to securely hold the field coils.

Field Coils.—The field coils, four in number, fit around and are held in place by the pole pieces. Each coil consists of 1080 turns of .102-inch diameter, No. 10 B. & S. double cotton-covered wire. The coils are form wound, thoroughly insulated with varnished cambric and tape and treated with insulating baking japan. Suitable terminals are provided on the coils for the electrical connections which are arranged for separate excitation.

Armature.—The armature is of the drum-wound type, **multiple connected.** The core is made up of steel laminations, mounted on a cast-iron spider keyed to the armature shaft, having suitable slots for the armature coils and air ducts for ventilation.

The armature coils are form wound, thoroughly insulated with varnished cambric and tape, and made water-proof with japan. Each coil consists of two copper bars .07″ × .42″ in multiple. There are 66 slots and 132 single coils, making four conductors per slot. The slots are thoroughly insulated and the coils held in place by bands of phosphor bronze wire.

Connection between the armature coils and the commutator bars is made by copper clips, the joints being soldered.

Commutator.—The commutator is of the ventilated type and consists of hard drawn copper segments 132 in number. These are mounted on a cast-iron spider and held in position by two cast-steel cone rings. Mica insulation is used throughout.

Brush Rigging.—The brush rigging consists of four insulated studs carried on an adjustable yoke. Each stud carries four brush holders with adjustable tension springs and each brush holder carries one carbon brush 1½″ × 1″ provided with flexible cables or pig-tails. Alternate brush studs are connected by bus rings.

Cables.—All cables are treated with water-proof compound, and brought through the frame through standard stuffing tubes. The field cables are 100 No. 25 B. & S. extra flexible brush-holder cables $\frac{1}{2}$ inch in diameter over all. The brush cables are 1000 No. 25 B. & S. extra flexible brush-holder cable 1.16 inch in diameter over all.

FIG. 124.—CB-32 Motor. Gen. Elec. Co.

Figs. 124 and 125 show the assembled and exploded view of motor known as CB-32.

Boat Crane Revolving Motor.

Classification.—This motor is series wound, of the armored type, and classified as GE-800-E, 20 H. P., 310 R. P. M., 80 volts.

Magnet Frame.—The frame is cast steel, rectangular in shape,

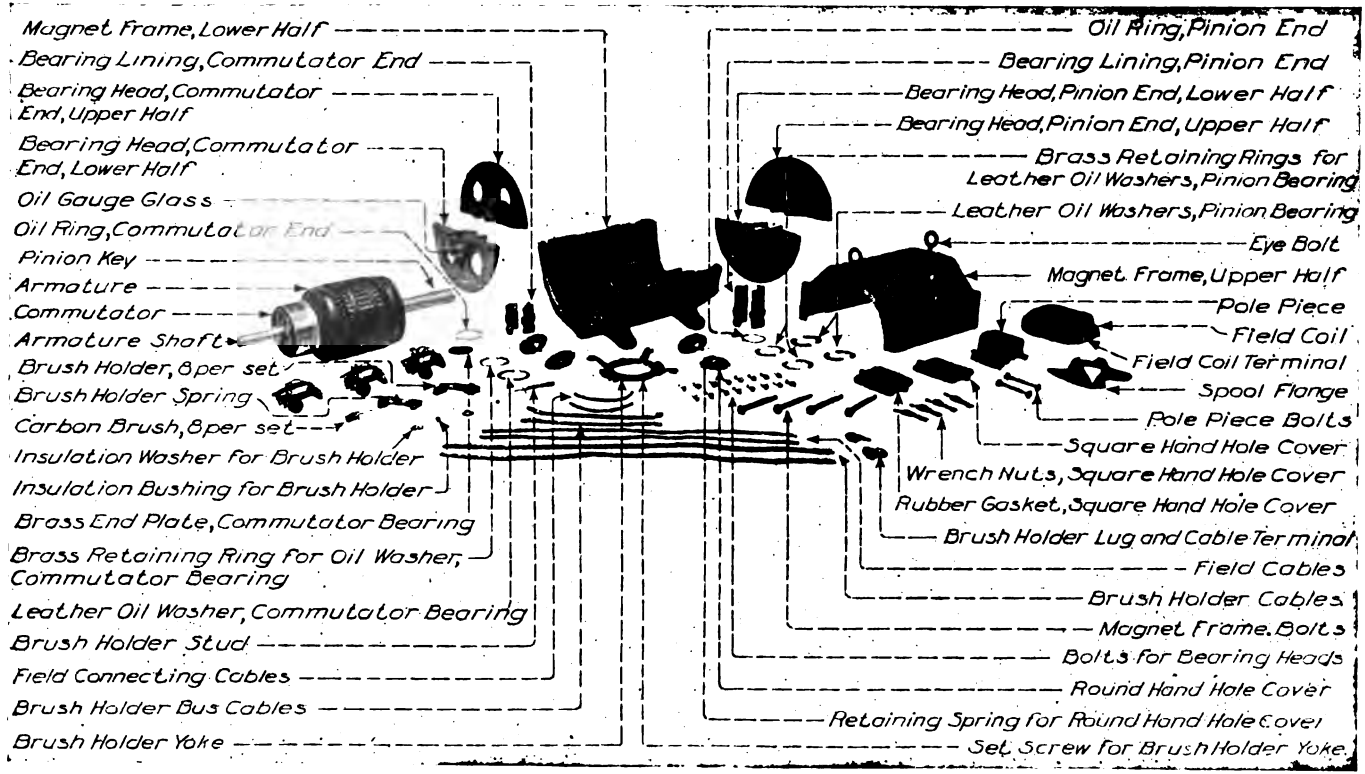

Magnet Frame, Lower Half
Bearing Lining, Commutator End
Bearing Head, Commutator End, Upper Half
Bearing Head, Commutator End, Lower Half
Oil Gauge Glass
Oil Ring, Commutator End
Pinion Key
Armature
Commutator
Armature Shaft
Brush Holder, 8 per set
Brush Holder Spring
Carbon Brush, 8 per set
Insulation Washer for Brush Holder
Insulation Bushing for Brush Holder
Brass End Plate, Commutator Bearing
Brass Retaining Ring for Oil Washer, Commutator Bearing
Leather Oil Washer, Commutator Bearing
Brush Holder Stud
Field Connecting Cables
Brush Holder Bus Cables
Brush Holder Yoke
Oil Ring, Pinion End
Bearing Lining, Pinion End
Bearing Head, Pinion End, Lower Half
Bearing Head, Pinion End, Upper Half
Brass Retaining Rings for Leather Oil Washers, Pinion Bearing
Leather Oil Washers, Pinion Bearing
Eye Bolt
Magnet Frame, Upper Half
Pole Piece
Field Coil
Field Coil Terminal
Spool Flange
Pole Piece Bolts
Square Hand Hole Cover
Wrench Nuts, Square Hand Hole Cover
Rubber Gasket, Square Hand Hole Cover
Brush Holder Lug and Cable Terminal
Field Cables
Brush Holder Cables
Magnet Frame Bolts
Bolts for Bearing Heads
Round Hand Hole Cover
Retaining Spring for Round Hand Hole Cover
Set Screw for Brush Holder Yoke

Fig. 125.—CB-32 Motor. Exploded View.

and cast in two parts to allow of free access to the armature and field windings. The lower half has suitable feet for fastening the motor to its foundation. The frame is entirely enclosed, but a suitable hand-hole provided with water-tight hinged cover allows for inspection and adjustment of the brushes.

Pole Pieces.—There are two **salient** and two **consequent** poles cast with the frame.

FIG. 126.—CB-25 M. 8, 30 H. P., 310 R. P. M., 125-Volt Ammunition-Hoist Motor with ED, 108 Disc Brake. Gen. Elec. Co.

Bearings.—The armature bearings have the lower part cast with the lower frame. The upper part is a removable cap containing a grease box, grease lubrication being used. An opening underneath provides for the escape of the grease after it is used. The bearing linings are of cast iron, babbitted, made in halves.

Field Coils.—The field coils are two in number fitting around the salient poles and held in position by bolts and clamping frame. Each coil consists of 33 turns of two .289-inch diameter copper wires, No. 1 B. & S., in parallel. They are asbestos and single cotton covered and the ends of the windings are soldered to suitable

terminals for making the electrical connections. The coil is then thoroughly insulated with varnished cambric and tape, and made water-proof with insulating baking japan.

Armature.—The armature is of the **drum-wound type, series connected.** The core is made up of steel laminations mounted on the shaft and firmly held between the armature heads. Suitable slots are provided for the armature coils and air ducts for ventilation.

The armature coils are form wound, thoroughly insulated with varnished cambric and tape, made water-proof with japan, and held in place by bands of phosphor-bronze wire. Each coil consists of

FIG. 127.—CB-34 Motor. Exploded View.

A = Magnet Frame, Lower Half.
B = Magnet Frame, Upper Half.
C = Bearing Head, Commutator End, Upper Half.
D = Bearing Head, Commutator End, Lower Half.
E = Bearing Head, Pinion End, Upper Half.
F = Bearing Head, Pinion End, Lower Half.
G = Bearing Lining, Commutator End.
H = Bearing Lining, Pinion End.
I = Pinion Key.
J = Armature.
K = Commutator.
L = Oil Ring, Commutator End.
M = Oil Ring, Pinion End.
N = Leather Oil Washer, Commutator End.
O = Leather Oil Washer, Pinion End.
P = Brass Retaining Ring for Oil Washer, Commutator End.
Q = Brass Retaining Ring for Oil Washer, Pinion End.
Qa = Field Coil.
R = Brass End-Plate Commutator Bearing.
Ra = Field Coil Terminal.
S = Spool Flange.
T = Pole Piece.
U = Pole Piece Bolts.
V = Rectangular Hand-Hole Covers.
Va = Rubber Gasket for Hand-Hole Covers.
W = Round Hand-Hole Covers.
X = Wrench Bolts for Hand-Hole Covers.
Y = Bolts for Bearing Heads.
Z = Bolts for Magnet Frame.
Za = Bolts for Bearing Heads and Magnet Frame.
Aa = Brush-Holder Yoke.
Ba = Brush-Holder Lug and Cable Terminals.
Ca = Brush-Holder Bus Cables.
Da = Field Cables.
Ea = Brush-Holder Cables.
Fa = Oil Gauge Commutator End.
Ga = Carbon Brush.
Ha = Brush-Holder Spring.
Ia = Brush Holder Complete.
Ja = Brush-Holder Stud.
Ka = Insulation Washers for B.-H. Stud.
La = Insulation Bushing for B.-H. Stud.

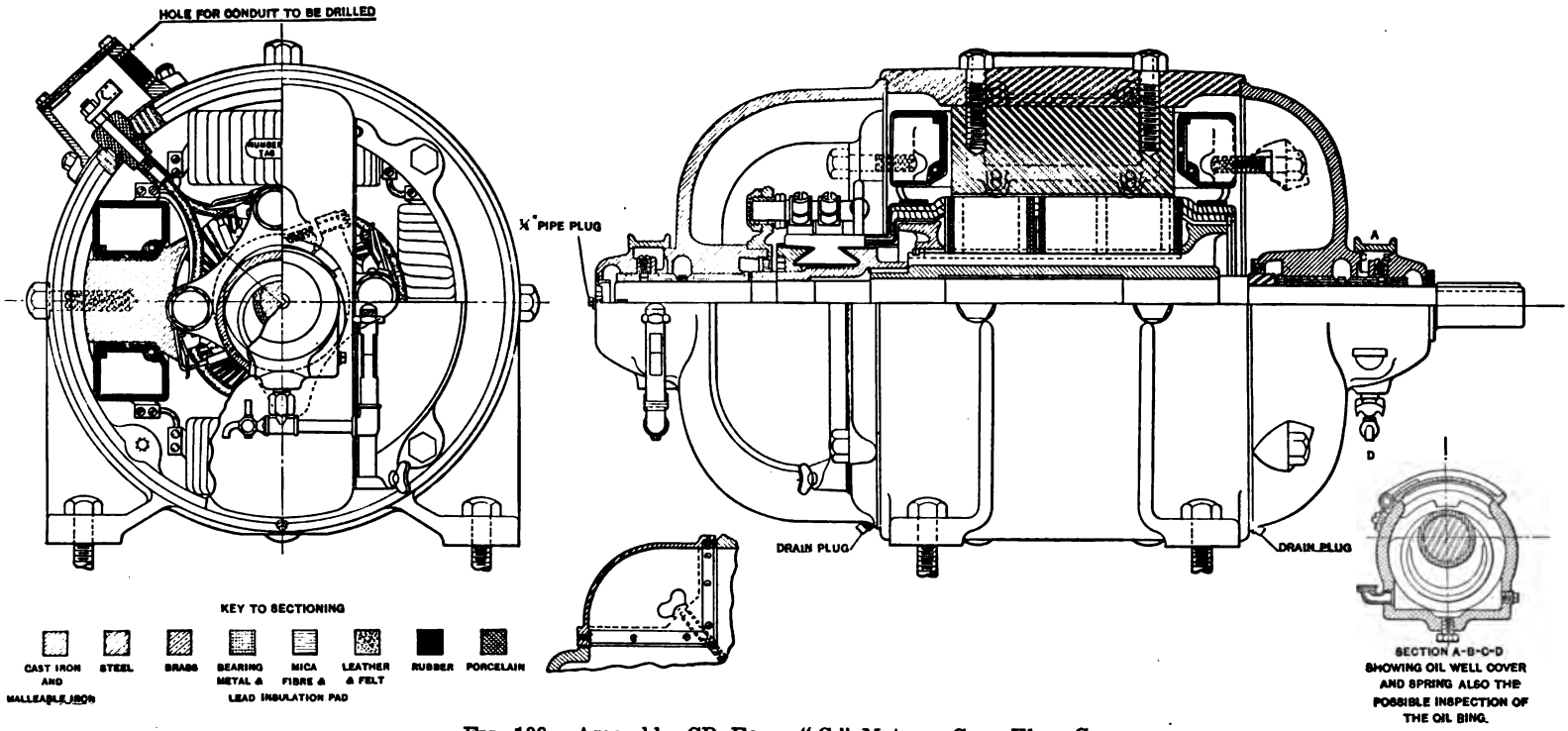


FIG. 128.—Assembly CR Form "G" Motor. Gen. Elec. Co.

one turn of four No. 10 B. & S. .1018-inch diameter copper wire in multiple, with extra heavy double cotton-covered insulation. There are 105 slots and 105 coils making two conductors per slot. The ends of the coils are soldered into the commutator bars.

Commutator.—The commutator is of the ventilated type and consits of 105 hard drawn copper segments on a malleable-iron spider and held in place by two malleable-iron cone rings. Mica insulation is used throughout.

Brush Rigging.—The brush rigging consists of four insulated brass studs mounted on an adjustable yoke. Each brush holder contains one brush $2\frac{1}{4}'' \times \frac{3}{4}''$ provided with a flexible cable or pig-tail.

Cables.—All cables are 300 No. 25 B. & S. extra flexible brush-holder cable, $\frac{1}{2}\frac{1}{2}$ inch outside diameter. They are treated with water-proof compound and brought out of the frame through drilled and tapped holes to which conduit may be attached.

Ammunition-Hoist Motor.

Fig. 126 shows an assembled ammunition-hoist motor fitted with electric brake.

Fig. 127 shows an exploded view of motor CB-34.

Fig. 128 shows a longitudinal section of CR motor, form G, and is of particular interest in showing all the different materials used in the construction as shown in the key to sectioning.

Blower Motors.

A design of motor for use with ventilating fans and blowers which finds extensive use on shipboard is shown in Fig. 129. It is made by the B. F. Sturtevant Company and is used with fans and blowers made by the same firm.

Description of Motors.—A motor, classified as M. P.-8 fan motor, is of the 8-pole type, and is especially designed to be direct connected to the side of the steel plate blowers of the centrifugal type. It is supported from the side of the blower by a cast-iron plate, which has three lugs for securing to the field frame or magnet ring of the motor. This cast-iron plate forms a part of the side

of the blower and is secured to the same by means of through bolts, which are easily removable.

Motor Parts—Magnet Frame.—The magnet frame or field ring consists either of a cast-iron ring, which is machined on the two faces and bored out on the internal surface to receive the pole

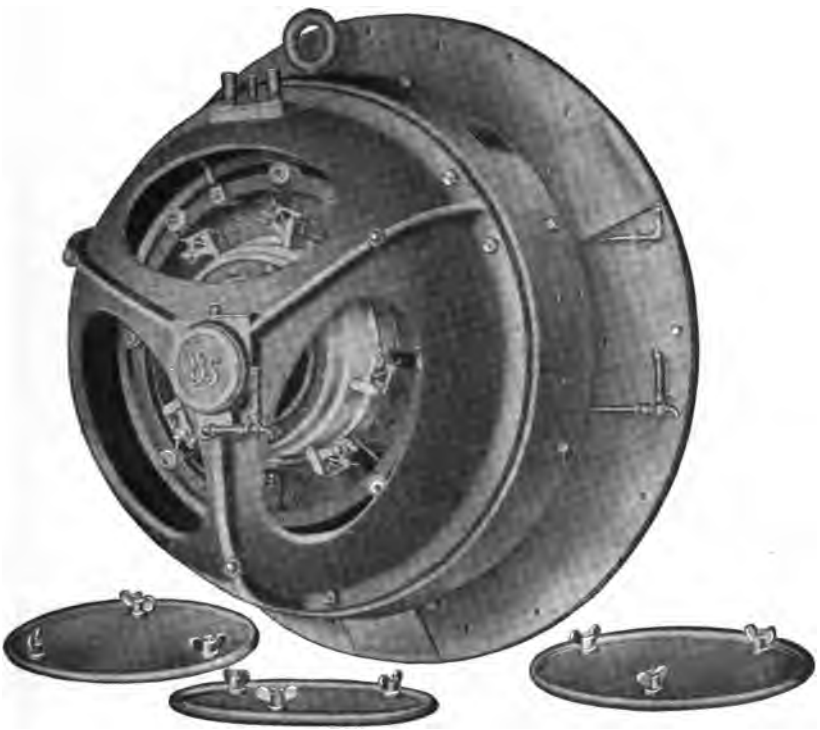


FIG. 129.—Sturtevant Eight-Pole Motor. Arranged for Attachment to Side Plates of Fan.

pieces, or of a wrought iron or steel casting which is machined all over both inside and out. The magnet ring is indicated on Fig. 130 by (1), and to the inner machined surface of which are secured by the bolts (27), the pole pieces (4).

Pole Pieces.—These pole pieces usually consist of Norway iron field cores with cast-iron shoes attached, but some are made of a solid steel casting.

Field Coils.—The pole pieces (4) are each encircled by the field coil (6), which consists of double cotton-covered magnet wire of highest conductivity, machine wound upon a form, after which it is thoroughly insulated by the following process:

1. Baked two hours at 150° F. to exclude all moisture.
2. Given two layers of heavy cotton tape.
3. Saturated with an insulating compound of highest possible moisture resisting qualities.
4. Baked five hours at 150° F.
5. Given two layers oiled rope tape.
6. Given two layers of finishing tape.
7. Finished with a heavy coat of quick-drying, black, oil, water and acid-proof insulating varnish.

After this treatment, and being placed on the pole pieces, a break-down test of 2500 volts is applied for one minute. These field coils are supplied with flexible leads, which are connected as hereinafter described.

The field coils of all these motors are made of double cotton-covered magnet wire.

Armature.—The armature (5) consists of a core (3) of laminated punchings of low steel clamped between two cast-iron flanges (25 and 26) the whole being wound upon a cast-iron spider (2) and the whole being held firmly in place by the screws (32). The laminated punchings are of No. 26 gauge, and have their slots for receiving the armature coils punched by the "step-by-step" process upon an indexing press. On account of the large diameter and open construction of this armature, together with the extremely narrow construction of the core ventilating discs through the core are not necessary, perfect ventilation being attained by the freedom with which the air may circulate through and about the entire armature.

The armature is of the form-wound, coil-drum type, having all coils duplicates and machine wound. Before being placed upon the core all coils are thoroughly insulated, additional insulation being placed in the slots as an extra precaution. This insulation consits of horn fibre or laminated rag board of varying thickness according to the work. For armatures of the size used on the 4-100

type M. P.-8 motors, the following method of excluding moisture and providing additional insulation is used: After the armature is completely assembled it is baked for from three to four hours at 150° F. to drive off all moisture, after which they are immediately thoroughly saturated with the Standard Varnish Works' Extra Black Coil Varnish. The armature is then again baked for about twelve hours at from 150° to 175° F. They are then allowed to cool slightly, after which they are finished with the Standard Varnish Works' Black Finishing Varnish. This process is the same for all armatures, except for the length of time required to bake them, which is less for smaller and more for larger motors.

Commutator.—The commutator (36) consists of pure drop-forged or drawn copper segments (7) clamped in a shell (17) by means of the screws (16) and thoroughly insulated by the micanite rings (37). Pure amber mica only is used between the segments.

This commutator when completed is mounted directly upon a projection from the armature spider, being held in place by a key (24) or four flat-head screws. The entire assembled armature is then forced upon the shaft of crucible steel (11), to which it is firmly secured by the key (10), upon the top of which is a set screw.

Bearings.—The bearings are of the ring-oiling type and consist of two composition sleeves (8 and 22), the rear bearing being of self-aligning construction and having two oil rings (33), while the front sleeve (22) has only one ring (13). The front sleeve (22) is held in place by two screw pins (14), and the back sleeve is held in the box (9) by screw pins, which are not shown upon the plate. The front bearing sleeve is supported in a tripod hanger or 3-armed yoke (23), which yoke is firmly secured to the magnet ring (1) by the six cap screws (31). Removing these cap screws allows this tripod hanger to be removed from the machine, after which the armature may be readily withdrawn from the field. Before doing this, however, the brush rigging must be removed from its supporting brackets (29). The back-bearing sleeve (8), as above stated, is supported in a cast-iron box or shell (9), which is secured to the cast-iron fan bracket of plate (28) by cap screws (15). This cast-iron fan bracket (28) supports the entire motor by being secured to the field frame by the cap screws (34), and

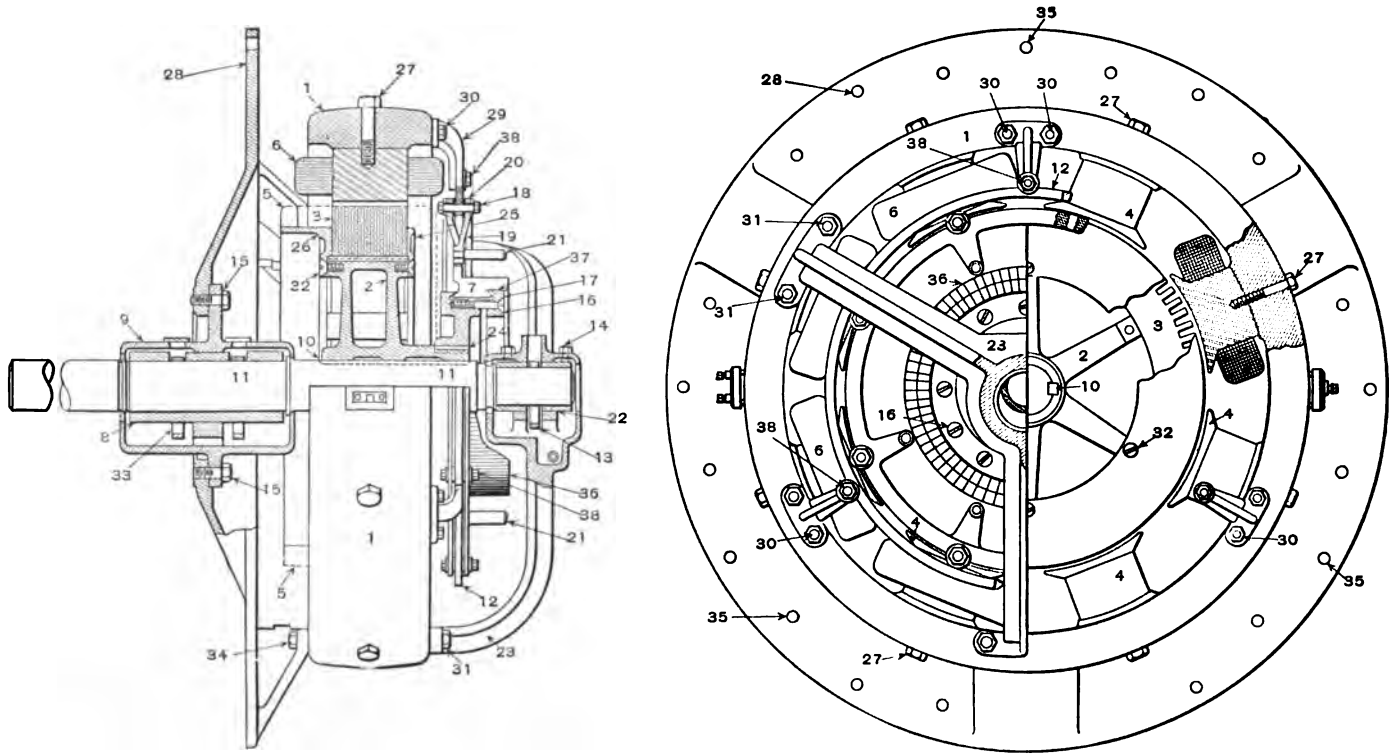


FIG. 130.—Type M. P.-8 Fan Motor. B. F. Sturtevant Company.

the entire machine is secured to the side of the fan by through bolts which pass through the holes (35).

Brush Rigging.—The brush rigging is of special construction and consists, first, of a guide ring (12), which is supported in the brackets (29), to which guide ring are secured by the through bolts (18), the two stud rings (19), to which are riveted the brush-holder studs (21). This brush rigging is so designed that all the studs of like polarity are attached directly to one stud ring, and all studs of opposite polarity are attached directly to the other. These two stud rings (19) are thoroughly insulated from each other and from the guide ring (12) by the hard rubber insulating washers and bushings (20). By loosening the small screws (38) this entire brush rigging is free to revolve around its axis.

CHAPTER XVII.

MOTOR STARTING AND CONTROLLING DEVICES.

Rheostats.

A rheostat is an arrangement of conductors for reducing the amount of electrical current passing through any circuit by interposing a resistance in it. A certain amount of the potential of the circuit is used up in overcoming the resistance of the rheostat and this represents the energy dissipated as heat. Rheostats should be used as little as possible, though in many cases, like shunt field regulators of generators they must be left in the circuit continuously.

In general, a rheostat consists of an electrical conductor properly supported, insulated, and provided with binding posts for making connection to the main line and to the apparatus to be controlled. The conducting materials generally used are German silver, nickeline or iron. Rheostats for regulating shunt field of dynamos ought to be made of German silver or some such alloy whose resistance does not change much with rise of temperature. Iron is not much used for resistances on board ship, on account of its liability to rust.

The conductor must be properly supported and well insulated from its supporting frame and must be so mechanically built as to allow effective ventilation, as the heat produced by the electrical currents must be carried away by radiation and convection.

Rheostats that are used only intermittently will carry a much larger current for a short time than those which are used continuously, as they will absorb a large amount of heat in a short time without becoming dangerously hot, but must be allowed to cool before being used again with large currents.

General Requirements.—The material of all resistances should be non-corrosive and not damageable by heating to a temperature of

150° C., or by salt air or salt water, and should not materially change its resistance with rise of temperature.

The insulating material should be non-combustible, non-absorbent and not damageable by moisture or by heating to a temperature of 150° C. The resistance should be so supported that it will not fall out in case it should be melted off or overheated at any point, and should be insulated from the supporting frame and the frame insulated from the hull of the ship.

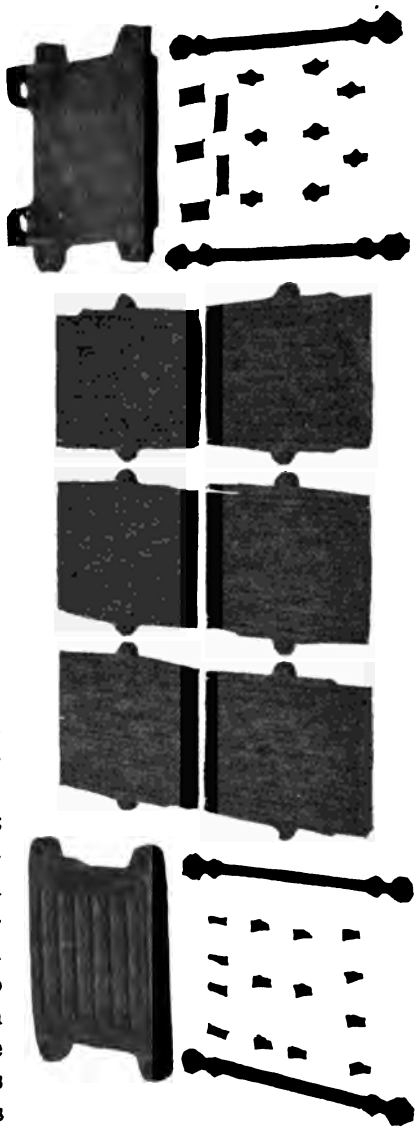


FIG. 131.—Exploded View of "PR" Rheostat. Gen. Elec. Co.

Packed Ribbon Rheostats.—This is the general form of rheostat used where large current capacity is required, as in turret ammunition hoists, gun rammers, and elevators, boat cranes, deck winches, whip hoists, etc., and is distinguished in description as "PR" rheostats.

These rheostats are built up in units and a characteristic completed one is shown in Fig. 132, while the detailed parts are shown in Fig. 131. It consists of two cast-iron end frames held in position by four round tie rods. Each end frame has a fire-brick with six slots

cemented to it. These fire-bricks support six panels of filling, differing somewhat in the various rheostats, but consisting essentially of malleable-iron top and bottom strips, provided with binding posts, between which are stretched back and forth several layers of German silver ribbon, the different layers being insulated from each other by means of asbestos. In addition to the German silver resistance, many of the panels have iron radiating pieces inserted between the various layers to help dissipate the heat. These rheostats are generally mounted so that the panels lie in vertical

FIG. 132.—Pressed-Ribbon ("PR") Rheostat. Gen. Elec. Co.

planes, allowing the air to circulate freely between them and thus carry off the heat. In order to prevent the absorption of moisture, these panels are dipped in japan which makes them water-proof.

The binding posts consist of lugs, provided with set-screws, cast on top and bottom plates. A binding post is provided at both ends of each panel for convenience in making connections. The panels are connected together by short copper strips fastened by screws to the top and bottom plates. The connections are usually made so that the six panels of the rheostat are in series with each other, but in some cases longer strips are used, so that the panels are connected

either two or three in multiple. These rheostats are designated by a serial number, as P. R.-218. If the panels of the rheostat are connected two in multiple the series number is followed by the letter A, as P. R.-218-A, and if connected three in multiple, it is known as P. R.-218-B.

The panels are insulated from the iron frames by means of the fire-bricks, but in order to give more insulation, insulating bushings are provided for the bolt holes in the feet of the rheostat

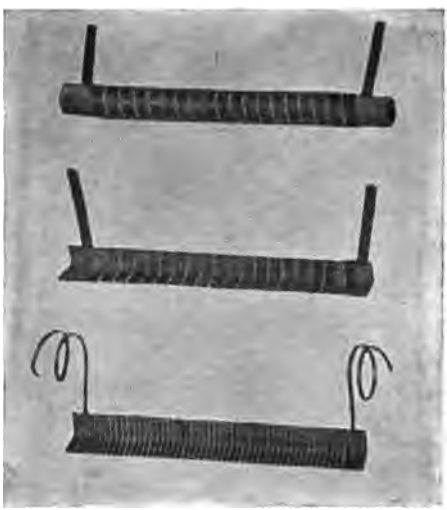


FIG. 133.—Wound Tube and Pressed Cards.

frame, so that each rheostat frame is insulated from its support.

Pressed Card Rheostats.—These rheostats are used where small current capacity but considerable resistance is required, as in the field circuits for controlling the voltage of generators or the speed of motors and in armature circuits for starting or controlling small motors. Resistances to take up field discharge on opening field switches are also of this type.

They are distinguished in description as "PC" rheostats. A completed unit is shown in Fig. 134, and various kinds of separate windings in Fig. 133.

This rheostat uses a filling made of German silver wire, wound on a mandrel covered with a tube of asbestos. After winding, the tube surrounded by the wire is pressed into a V-shaped trough or card, the turns of wire being sufficiently far apart to prevent them from becoming short-circuited. Several of these cards are packed together and held between pressure plates made made of cast iron thoroughly insulated with mica. The whole bunch of cards thus clamped together is supported by rods passing through the pressure

FIG. 134.—Showing Iron Plates Between Cards.

plates which are held in place by nuts. These rods are then fastened in cast-iron brackets or legs, to which the slate carrying the contact blocks of the rheostat is also attached. After the cards have been assembled, they are thoroughly treated with japan to make them water-proof.

Enclosed Card Rheostats.—These rheostats are for the same general purposes as the pressed card type and are somewhat similar in construction. They are designated as "EC" rheostats.

The rheostat frames are made up of two perforated cast-iron end pieces and two perforated sheet-iron side plates. The resistance

units are mounted within the frame. The illustration in Fig. 135 shows an enclosed card unit in its four stages of construction.

Each resistance unit consists of an asbestos tube around which the resistance wire or ribbon is wound. The tube is then pressed flat and enclosed in an asbestos-lined japanned sheet-metal casing. These units are assembled on mica insulated supporting rods and are spaced and insulated from one another by mica washers.

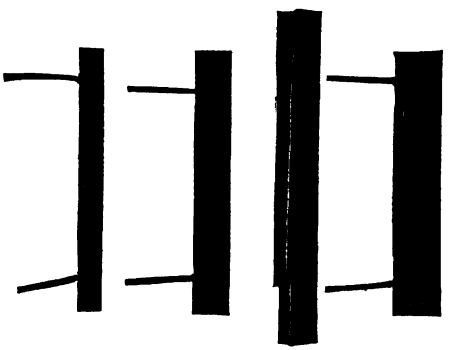


FIG. 135.—"EC" Rheostat Elements.

Resistances are secured by using two or more units, in series, and higher carrying capacities are obtained by connecting plates in parallel.

The button terminals are shown in the diagram of connections in Fig. 136.

The switches of these rheostats have three rows of contact buttons. The short arm of the switch is attached to the hand-wheel, through the shaft, and bears upon the inner row of contact buttons. The long arm revolves freely about the shaft and is insulated from the short arm. Upon the long arm is a contact brush connecting the outer and intermediate rows of contact. The intermediate and inner rows or dials are tied together. When both arms are in line, one over the other, on the first buttons of the dials, the resistance is all short-circuited. The desired amount of resistance can be cut in by turning the handle to the right. When the short arm has made half a revolution a projection on it strikes a pin in the long arm and carries it along, inserting the resistance connected to the

outer dial. The reverse movement causes the short arm to strike the long arm direct, after making half a revolution and carries it back.

The rheostat is so arranged that one-half revolution of the short, or inner, contact arm cuts in or out a resistance equal to that in one step of the outer dial thus permitting fine regulation.

"CG" Rheostats.—The "CG" or cast grid rheostat, shown in detail in Fig. 137, consists of a number of cast-iron resistance units

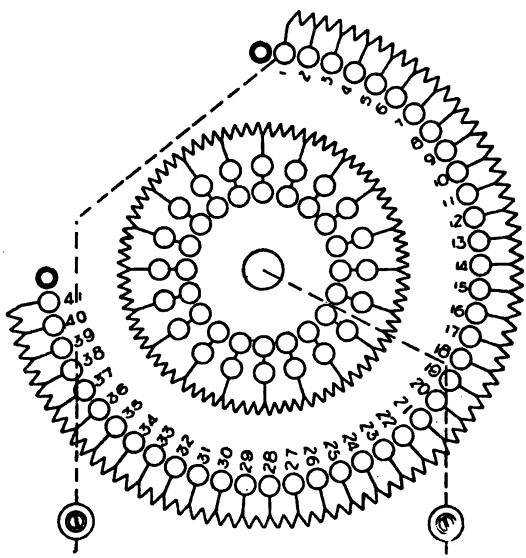


FIG. 136.—Connections of "EC" Rheostat. Gen. Elec. Co.

of the shape shown in the photograph, mounted upon insulated rods, the latter being held in cast-iron end frames.

The developed length of these grids is the same for all resistances, the difference in resistance being obtained by varying the cross-section of the casting.

Bosses, through which the supporting rods pass, are cast at one end of these grids, these being somewhat thicker than the remaining material, so that when the grids are mounted upon the supporting rods, they are separated by an air space, the connection

between the various grids being made at the above-mentioned bosses.

Mica washers are inserted between these bosses where it is desired to separate the grids, and provision is made for connecting leads by means of cast-iron terminals, which are inserted between the bosses above described.

This type of rheostat possesses a great advantage of having large intermittent capacity, since the resistance material can be heated if necessary to very high temperature, and the heat thus generated is

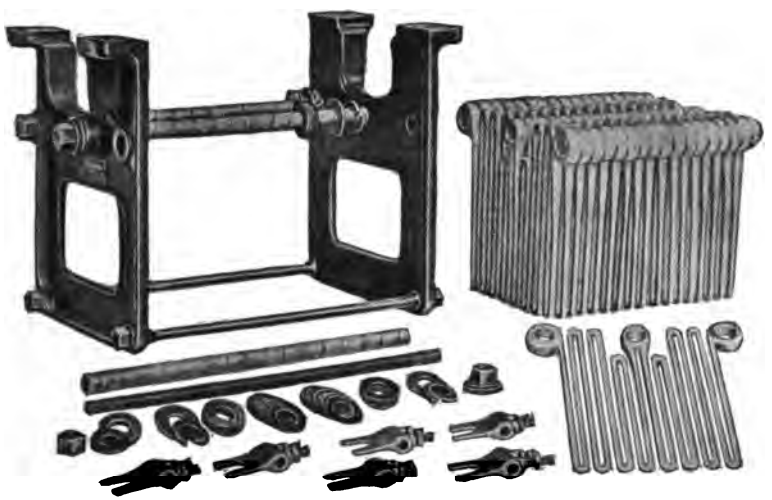


FIG. 137.—"CG" Rheostat. Disassembled View. Gen. Elec. Co.

rapidly dissipated by the large radiating surface of the grids. This design of rheostat permits wide range of resistance capacity determined by the size of grid and the use and arrangement of these grids in series or multiple.

"IG" Resistance.—The form "IG" resistance, shown in the upper part of Fig. 138, is similar to the form "CG" rheostat above described, the principal difference consisting in the shape and dimensions of the grids.

They are used ordinarily for motor starting resistance, in series with the armature circuit.

"ES" Resistances.—The "ES" or edgewise wound resistance unit, shown in Fig. 139, consists of a resistance ribbon, rectangular

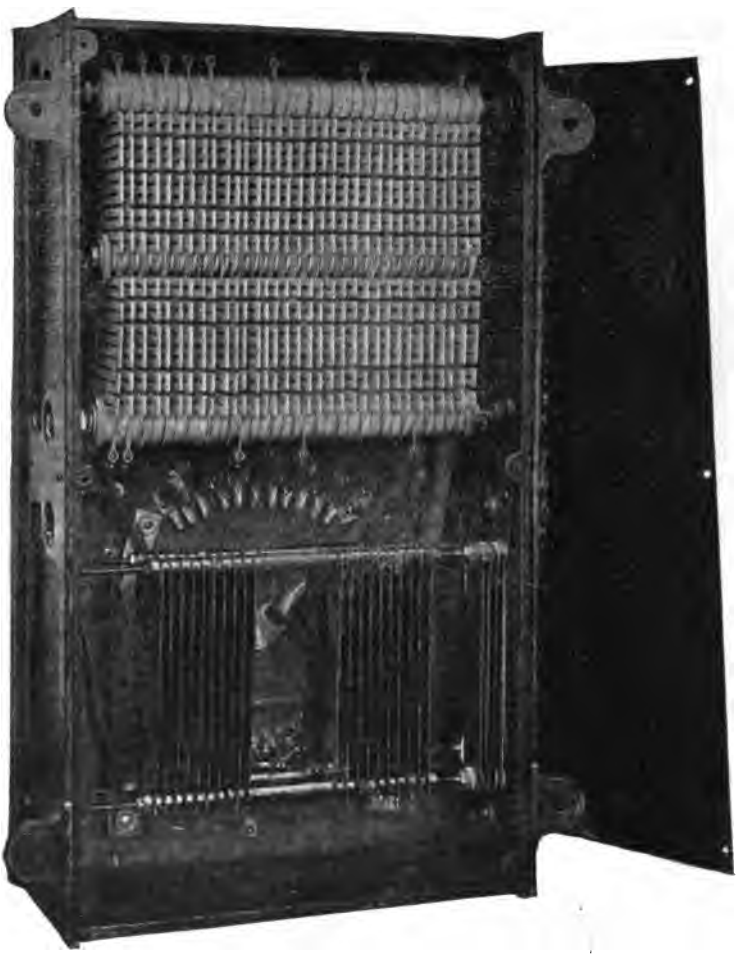


FIG. 138.—Type UY, Form K, 60 H. P. Combined Starter and Regulator Panel. Gen. Elec. Co.

in section, wound on edge around a supporting tube, from which it is insulated ordinarily by asbestos.

After the spiral has been wound, the turns are separated and the entire unit dipped in a silicate, which, when hardened, separates the whorls and covers the outside of the resistance, making it solid and able to withstand a very high temperature.

Form "P" Resistance.—The form "P" resistance, shown in Fig. 140, consists of an asbestos tube supported at the ends by porcelain bushings, upon which the resistance material is wound, the whole tube being coated by a silicate after it is completed.

This unit will stand a very high temperature without injury and has a large radiating capacity. It is made in several standard sizes, and in special cases, taps are brought out to meet requirements, although ordinarily there are but two taps, one at each end.

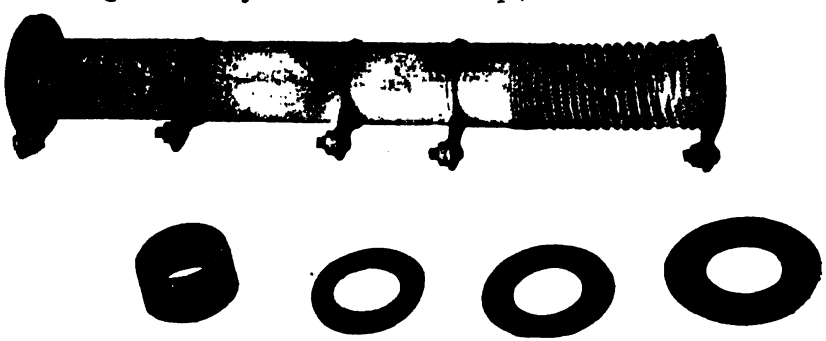


FIG. 139.—Edgewise Wound Resistance Coil. Gen. Elec. Co.

Rheostats for Controlling Panels.—Rheostats for the controlling panels of ventilating motors of the Cutler-Hammer make are known as the "sand box" type. The resistance is wound on a thin slate slab located in the center of an iron box and surrounded by glass-makers' sand. There is a filling hole plugged by a pipe plug. The front of the box is of cast iron for the small rheostats and slate for the large ones.

The contact buttons are located on the front of the box, insulation with mica in the case of the small rheostats with metal fronts. Wire connectors connect these contacts with the switch contacts on the front of the panel. The rheostat is insulated from the panel framework by hard rubber bushing.

Other forms of rheostats are made with the resistances coiled on

porcelain tubes or embedded in enamel. In the latter form the resistance is generally in the form of corrugated ribbon to allow it to be coiled in a small space and to present greater radiating surface for the heat produced.

Liquid Resistances.—Although these find no use on shipboard they are useful in the laboratory to provide non-inductive loads when testing generators. They generally consist of iron plates immersed in water, or salt or soda solutions, and the resistance may be regulated either by moving the plates nearer together or farther

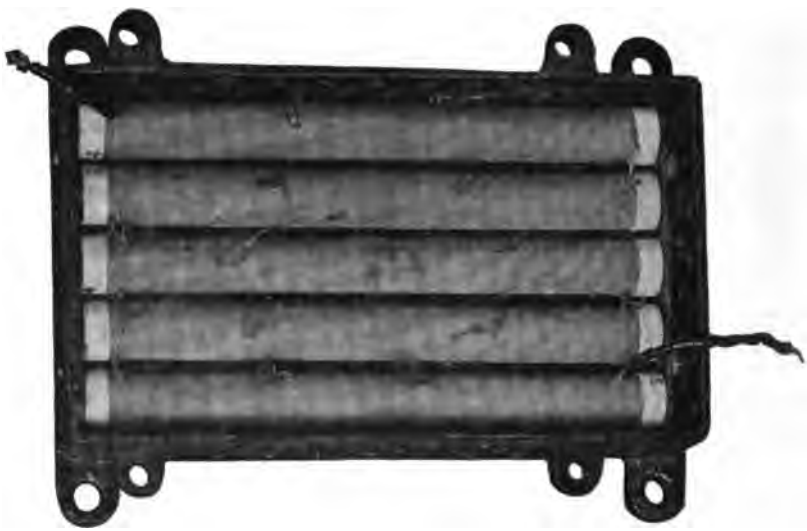


FIG. 140.—Type FM, Form "P", Field Rheostat. Gen. Elec. Co.

apart from each other, or by immersing a smaller or larger area of plate, effected by having wedge-shaped plates.

The chief troubles with these resistances are the evaporation of the water and the creeping of the dissolved salts. The creeping can be avoided by smearing vaseline just above the liquid level.

Starting and Controlling Devices.

These are devices installed between the power supply mains and motors for starting or stopping them, reversing the direction of the armature or for changing their speed.

They are used where particularly heavy currents are not required, as in chain ammunition hoists, hull ventilating motors, all separate ventilating or smoke-blower motors, in separate machine motors, and all auxiliary motors used for independent purposes, as laundry work, meat choppers, ice-cream freezers, potato peelers, printing presses, etc.

Principles of Automatic Rheostats.—There are several varieties of these devices. One form used for motor starting has a magnetic

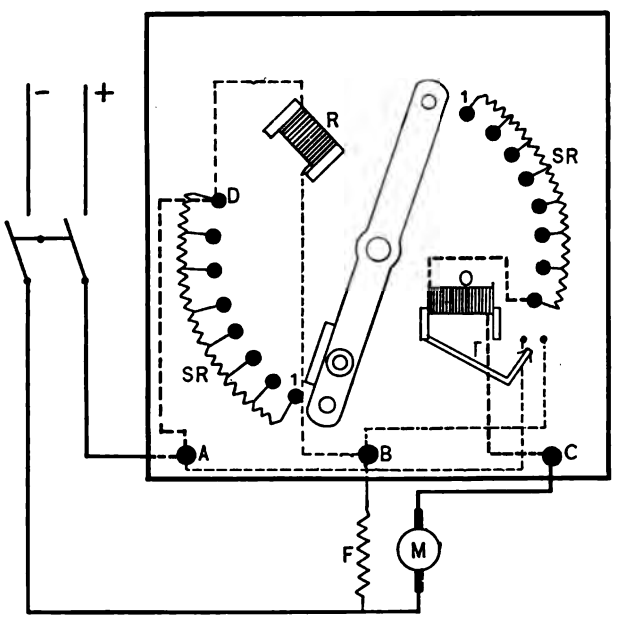


FIG. 141.—Starting Resistance.

device to throw the starting resistance into series with the armature in case the line voltage is removed for any cause. Others have, in addition, a device to throw the starting resistance into the armature circuit and thus slow or stop the motor in case of a dangerous overload. Others have starting devices in which the resistance is cut out automatically.

Fig. 141 illustrates a form of rheostat combining the principles to be satisfied for starting rheostats for all shunt motors.

The starting resistance in series with the armature *M* is shown marked *SR* and its necessity has been explained under Operation of Motors. The shunt field connection runs from *D* on the + side of the supply mains to *B* through the magnet *R*, thence through the motor field *F* to the — main. It will thus be seen that the field is fully energized when the switch in the main line is closed, and this is an important principle in all starting panels or rheostats. If by any chance there was only a weak field on starting, it would result in an excess of current and heavy sparking.

When the main switch is closed and the field excited, a movement of the rheostat arm to the right making contact on point No. 1 connects the main line to the armature through the starting resistance on the left, through the arm, through the starting resistance on the right, around the magnet *O*, through terminal *C* to armature *M* and to the — line.

The operation of starting the motor is, after contact is made on contact 1, to slowly move the arm over the successive contact points, cutting out resistance, until it rests on the last contact, when all resistance is out and the arm brings up against the armature of the magnet *R*. Owing to the field current flowing around *R*, its armature is made strongly magnetic, holding the arm of the rheostat firmly by its attraction against the action of a spring tending to return it to its original position.

If by any chance *R* becomes demagnetized by the field current failing, its armature will no longer attract the arm and the spring will throw it back to the "off" position breaking the armature circuit and stopping the motor. As this happens when the current or E. M. F. fails, *R* is called the **no-voltage release magnet.**

The main current flows around the magnet *O*, and if the current rises above a certain amount, the magnet will attract the tripper arm *T*, which will close the circuit between two points shown which are connected to the terminals of the magnet *R*. This will short circuit this magnet, and as it then has no voltage, it will release the starting arm which will fly back to the "off" position. This serves the double purpose of opening the circuit due to an overload and resetting the arm, so it is in the right place for restarting. It also serves the purpose of short-circuiting *R* if the starting arm

is moved too rapidly and allowing too much current through the armature before it develops its speed. In this case, the arm will not be held against *R* when it is released by the hand but will fly immediately back to its starting position. For the reasons stated, *R* is called the **overload magnet.**

The starting resistance of this type of controller is only made to withstand the current necessary to start the armature, so under no circumstances should any attempt be made to control the speed by securing the arm on any intermediate contact.

In some forms, the overload magnet is omitted and its place taken by fuses in each side of the main line, and in others, both the overload magnet and fuses are used.

To stop, always open the main line switch first, and the starting arm will fly to " off " when the field current has died down.

Navy Standard Controlling Panel—Type U. S. (made by the General Electric Company, Schenectady, N. Y.).—The following applies to a standard controlling panel designed for use with motors supplied to the government.

Classification.—The general design of panel is classified Type U. S., Form A, Form B, etc., the form letter depending upon the electrical connections which are different according to the kind of apparatus to be operated and to the method of operation.

Construction.—The dimensions and general design of this panel for motors of 10 horsepower and less are shown in Fig. 142.

Panels for motors larger than 10 horsepower are of similar design and operation but of increased dimensions.

The panel for 10 horsepower and less consists of an enameled slate 12″ wide × 24″ long × 1″ thick, which is supported on iron side frames. When used on shipboard this can be enclosed by sheet-iron doors opening to give convenient access to the front of the panel.

The enclosing casing is carefully japanned to prevent rust, the doors being supplied with a Yale and Towne padlock, furnished with duplicate keys.

The operating parts are on the front of the slate, and the resistance is behind the slate and supported by the side frames.

The operating parts, common to all panels, are as follows:

Switch.—The main switch is at the bottom of the board. It is single-pole and in case of reversible motors is double-throw, interlocking with a double-pole double-throw switch so arranged that the field cannot be opened while current is on the armature.

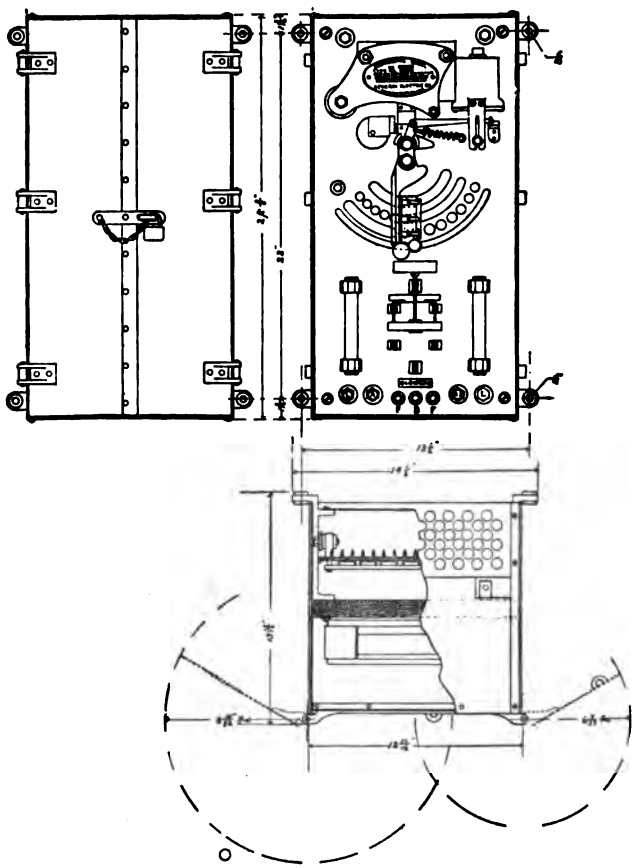


FIG. 142.—Navy Standard Controlling Panel—Type U. S. Gen. Elec. Co.

Rheostat Switch.—The rheostat switch consists of an arm carrying several contact brushes which bear upon contact rings or rheostat blocks, as shown in the Diagram of Connections, Fig. 143. This arm, when thrown to the extreme right, closes a single-pole

circuit breaker at the top of the panel. This is held closed by a retaining magnet at the upper left-hand corner, the circuit of which is closed by pressing down a push button near the hand of

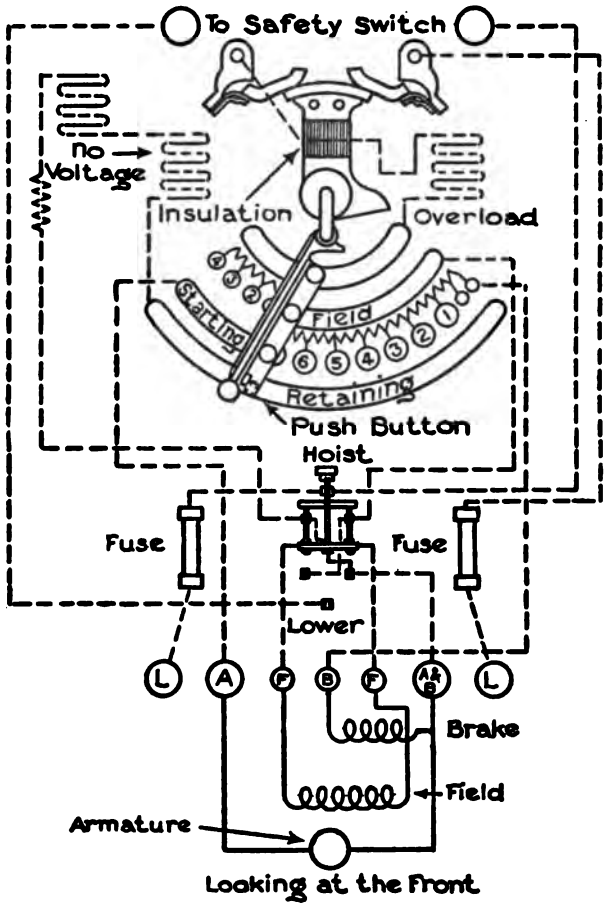


FIG. 143.—Connections of Controlling Panel for Chain Ammunition-Hoist Motor—Type U. S. Form A. Gen. Elec. Co.

the operator. The contact ring is so designed that this plunger will open this circuit and trip the circuit breaker if the hand is removed before the rheostat arm is on a running contact.

Circuit Breaker.—The single-pole magnetic circuit breaker at the top of the board is set by the action of the rheostat arm and is held closed by two latches, one of which can be released by the overload coil when the current exceeds that for which the breaker is set, and the other released by the no-voltage coil. This circuit breaker is opened by two helical springs one released by each latch.

The wearing parts of the circuit breaker are renewable and can be easily inspected by taking off the four bolts or nuts at the corners of the pole pieces. When the pole piece has been taken off, all parts of the breaker can be readily removed from the slate without the use of special tools.

Fuses.—Two enclosed fuses are supplied to protect the panel against short circuits.

Terminals.—The terminals consist of blocks behind the slate to which the wires are attached and which are held in position by screws projecting through the slate thus allowing connections to be easily made after the panel is installed.

Resistances.—The resistances behind the slate are designed to meet the special requirements of the individual panel.

Insulation.—The switch parts are mounted on a slate base which has been thoroughly baked and treated with japan and polished. Adjacent parts of the apparatus will stand a test of 1000 volts alternating for one minute.

The feet of the frame are supplied with insulating bushings if required, which will stand 1500 volts alternating.

Non-Corrosive Parts.—When furnished for use on shipboard, all small parts not in magnetic circuit are of non-corrosive material, and where necessary moving steel parts are copper plated.

Weight.—The weight of the panel is approximately one hundred (100) pounds, slight variation being occasioned by difference in resistances required for various kinds of work.

Description of Operation.—This panel is designed to protect the apparatus against the following conditions:.

(1) Legitimate overload.
(2) Failure of voltage on line.
(3) Excessive rush of current occasioned by too rapid starting.
(4) Running on resistance which is only designed for starting.

These features are accomplished by the fact that the circuit-breaker arm, which is released either by overload or no voltage can only be set by the rheostat arm when it is at the starting position and will not remain closed while the arm is on starting resistance blocks if the hand of the operator is removed and the contact at the retaining segment broken. If this occurs the no-voltage coil circuit is opened and the circuit breaker released.

If the panel is used with a reversible motor, the main switch interlocks with the double-pole double-throw field reversing switch so that it is impossible to close the main line until after the field circuit is closed, or to open the field before the main line is opened.

Directions for Operation.—

To start:

1. Close the main switch at the bottom of the board.

2. Move the rheostat arm as far as possible to the right, setting the circuit breaker.

3. Press down on push button and move the arm slowly to the left until the button rests in the raised surface of the contact ring.

If the arm is moved too rapidly, or if the current fails, the circuit breaker will open.

To stop:

Open the single-pole single-throw switch.

This will release the circuit breaker which is in the side of the line. It is impossible to re-set this until all starting resistance has been placed in the circuit.

Speed Controlling Panel.—The controlling panels previously described have no arrangement for controlling the speed of the armature, but the following description illustrates this point. This form is used generally on ventilating fans, by which the number of revolutions of the fan is controlled.

The description is of a panel of the Cutler-Hammer type and the connections are shown in Fig. 144.

This type of panel is fitted with a main line switch, enclosed fuses, a starting rheostat with automatic no-voltage and overload release, and a field rheostat. It consists of an enamelled slate of suitable size, supported on iron side frames when enclosed; the back is of galvanized sheet iron and the sides and front of perfo-

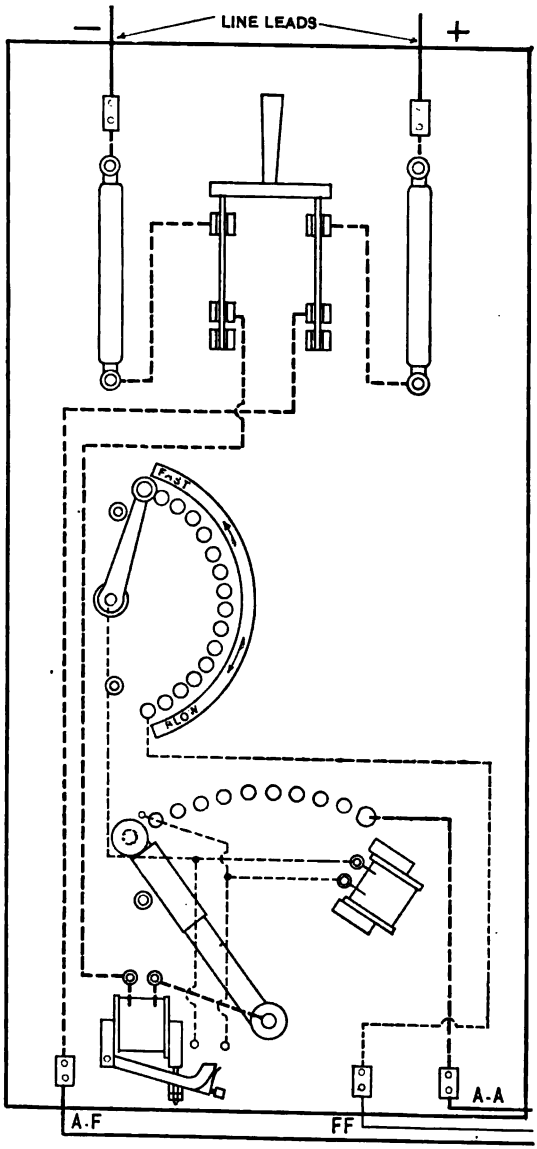


FIG. 144.—Speed Controlling Panel. Cutler-Hamner Co.

rated sheet brass. The two doors at the front of the panel are fastened by padlocks. The operating parts are on the front of the slate, and the resistances are behind the slate and supported by the side frames.

Switch.—The main switch is at the top of the panel and is of the double-pole single-throw type.

Rheostat Switch.—This consists of an arm carrying a single contact brush bearing on contact blocks as shown in the figure. When the motor is not running, the arm is held in the position shown by the action of a spring.

Field Regulating Rheostat Switch.—This consists of an arm carrying a single contact brush bearing on contact blocks, as shown in the figure, and by varying the position of this arm the resistance of the field circuit is increased or decreased, thus increasing or decreasing the speed of the motor. This is only fitted for motors having speed control.

Fuses.—Two enclosed fuses are supplied to protect the panel against short circuits.

No-Load Release Magnet.—This magnet is placed in the field circuit and when the starting arm is on the "full on" position, this magnet retains it in position against the action of the spring tending to return the arm to the off position. If the line voltage is lost at any time, this magnet releases the arm and it is returned to the off position.

Overload Release Magnet.—This magnet is in the main circuit, and when an excessive current passes through it, it acts upon a plunger which in turn acts to short circuit the "no-load" magnet, thus releasing the starting rheostat arm.

Terminals.—The terminals consist of blocks behind the slate to which the wires are attached and which are held in position by screws, projecting through the slate, thus allowing connections to be easily made after the panel is installed.

Resistances.—The resistances behind the slate are designed to meet the special requirements of the individual panel.

Insulation.—All panels are insulated from the ship by hard rubber blocks and bushings.

Description of Operation.—This panel is designed to protect the motor from the following conditions:

(1) Legitimate overload.

(2) Failure of voltage on line.

(3) Running on resistance which is only designed for starting.

These features are accomplished by the fact that the circuit-breaker arm, which is released by either overload or no-voltage will only be set and held when in the full running position by the no-voltage magnet. If the arm is released before it reaches this point, it is at once returned to the off position by the action of the spring mentioned above under "Rheostat Arm."

Directions for Operating.—To start: If the motor has speed control, shift the speed-control rheostat arm to the extreme position marked "slow" on the panel. Then close the main line switch. Then move the starting rheostat arm to the first contact point. After allowing it to remain for a moment on this point, move it to the second point and then to the third, etc. If the motor has not started when the arm reaches the fourth line segment, open the main line switch and ascertain what the trouble is, first making sure the voltage is across the mains, and then making a close examination into all the connections of the machine which are liable to become loose or displaced. As soon as the motor commences to revolve this starting arm should be moved slowly from one segment to the next until it has reached the "full on" position, at which point it will be firmly retained by the small magnet. After the motor has arrived at full speed with the starting arm at "full on," the speed may then be increased by slowly moving the speed-controlling arm from slow to fast. When necessary to reduce the speed of the motor, by moving the speed-controlling arm from fast to slow, this should be done slowly in order to allow the motor to drop in speed. If moved too rapidly, the motor will act as a generator, due to its momentum, and generate a voltage in excess of that upon the line, which is liable to blow the fuses, due to the excessive rush of current.

To stop: To stop the motor, open the main line switch and allow the starting rheostat to take care of itself. The rheostat arm will not be immediately released, but will be held in place until the

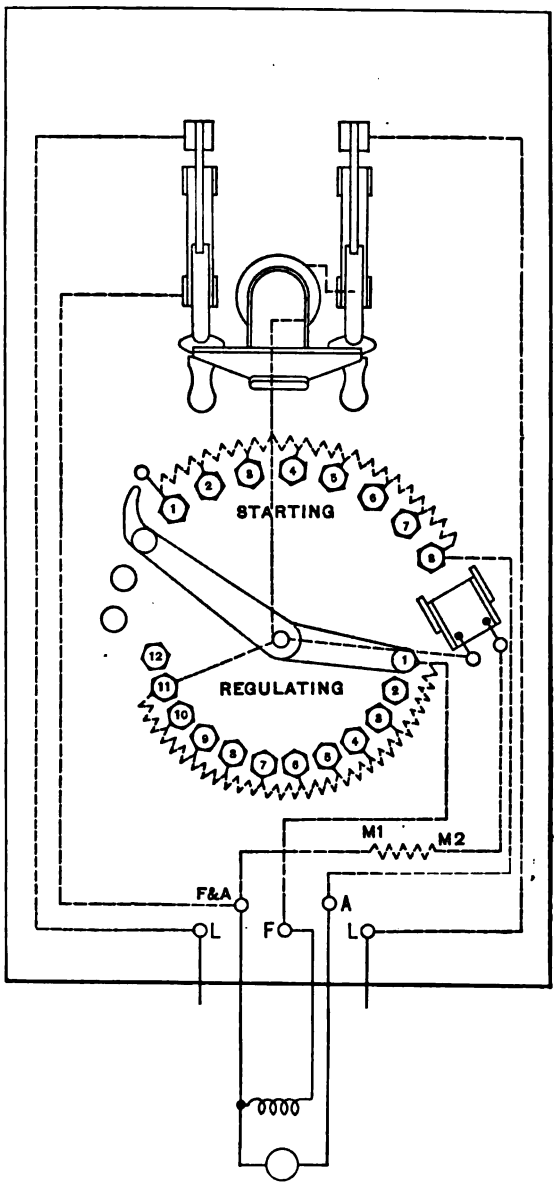


FIG. 145.—Starting and Regulating Panel. Gen. Elec. Co.

motor is slowed down somewhat, when it will fly to the "full off" position.

Never attempt to stop the motor by forcing the rheostat lever to "full off" position; always open the main line switch first. Before starting again, be sure that the speed-controlling handle is at the "slow" point.

Type CR, Form M-3.

This type of starting panel for starting and field control, manufactured by the General Electric Company, is shown in Fig. 145.

From descriptions of preceding controlling panels, the action of this one will be readily understood.

Separate Speed-Controller Rheostat.—These are used in connection with a separate starting panel to control the speed of motors, by varying the field of the generators supplying the power, on the principle of the Ward-Leonard system of control previously explained.

The speed-control rheostat regulates the field of the generator of a motor generator, the starting panel being used to control the current of the motor of the motor generator.

The starting panel presents no special features, but a description is given of the speed-control rheostat as manufactured by the General Electric Company and applied to elevating equipments for 8, 10, and 12-inch guns.

The general connections are shown in Fig. 146.

The resistances are connected between contact points shown in the upper and lower semicircles. Each one of the upper points is connected to the one directly underneath it as indicated by the dotted lines connecting the outside ones. The ends of the generator field windings are connected, one to each of the two semicircular conductors, while one end of the supply main is connected to the inner circular conductor. The heavy short full lines are contact pieces, the right-hand one making contact between the inner and outer circular conductors, and the left-hand one between the outer semicircular conductor and the circular ring of contacts. They are moved by the starting arm. These contact pieces are secured on the outside of a toothed wheel and revolve with it, into which gears

a toothed arc, to which the handle is secured, so when the handle is moved down, revolving the arc to the right, the gear wheel turns to the left, carrying the right-hand contact piece up and the left one down, as viewed in the figure.

The direction of the current is as follows: Suppose handle is moved down. Current then flows from the starting panel to the

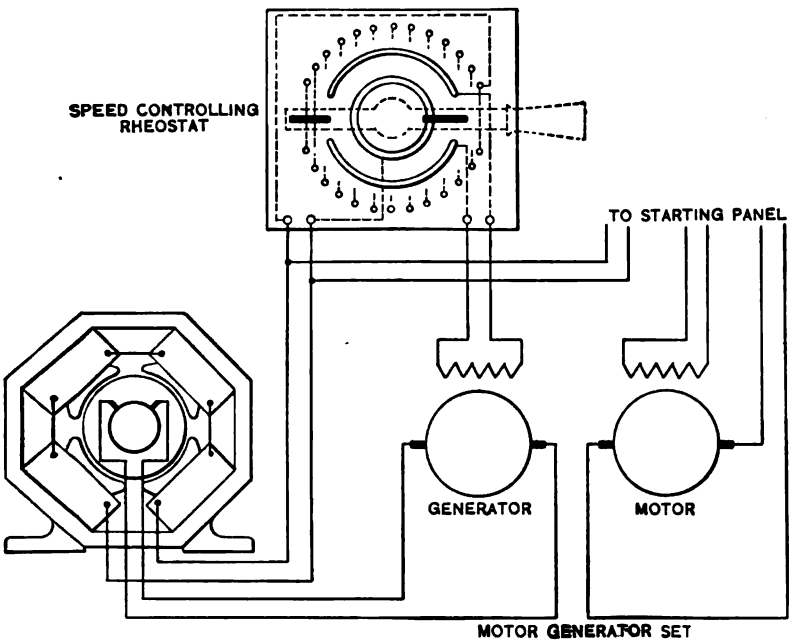


FIG. 146.—Speed-Controlling Rheostat. Gen. Elec. Co.

left-hand lower terminal, up and around to the upper right-hand contact in the upper semicircle, then through the resistances, through the left-hand contact piece to the lower semicircular conductor, then through the generator field by way of the two terminals in the right-hand lower corner, then to the upper semicircular conductor, from that to the inner conductor and out by the right-hand lower terminal on the left and back to the starting panel.

By moving the handle further, more resistance is cut out and

consequently the generator field is changed, thus varying its voltage, which is that impressed on the working motor, and which changes the speed of the motor.

By moving the handle the other way, the direction of the current in the generator field is changed, consequently the current through the generator and motor changes, reversing the direction of the latter.

Automatic Motor Control.—It may happen that it is desired to control the arm of the motor-starting resistance automatically, so that the motor may be started and stopped by the simple operation of opening or closing a switch. Such a case arises in motor control in wireless telegraphy where the operator may wish to start his sending apparatus without leaving his station at the receiver.

This form of control is illustrated in Fig. 147. *M* is the motor armature of the motor generator, *S* the series field, and *S'* the shunt field with its rheostat *R*.

When switch 1 is closed, circuit to the power mains is established through the shunt field. 2 is a single-pole switch which may be removed some distance from the rest of the control circuits. When 2 is closed, the circuit is completed through the solenoid magnet 3 and the resistance 4, and when 3 is energized, its plunger is pulled up, and the circuit breaker 6 then completes the circuit through the armature *M*, series field *S*, resistance 5, and starting arm 8. At the same time that the armature circuit is established, circuit is established in the solenoid magnet 7 and resistance 9, and as the magnet is energized, its plunger is drawn up, pulling up the starting arm 8, which gradually cuts out the resistance 5, allowing the motor to attain its full speed. The plunger of the solenoid 7 works against a dash pot *P*, which makes its motion gradual so that it is not pulled up with a sudden jerk.

To stop the motor, it is only necessary to open switch 2 when the magnet 3 becomes demagnetized, and the plunger no longer held up, drops by its own weight, opening the armature circuit, and at the same time opening the circuit of the solenoid 7. The plunger of this solenoid then drops and the starting arm returns to its original position throwing in all resistance in 5, and the whole circuit is then ready for the operation of starting again by the operation of closing switch 2.

When the circuit breaker 6 drops, it short-circuits the armature brushes through the resistance 10, bringing the armature quickly to rest.

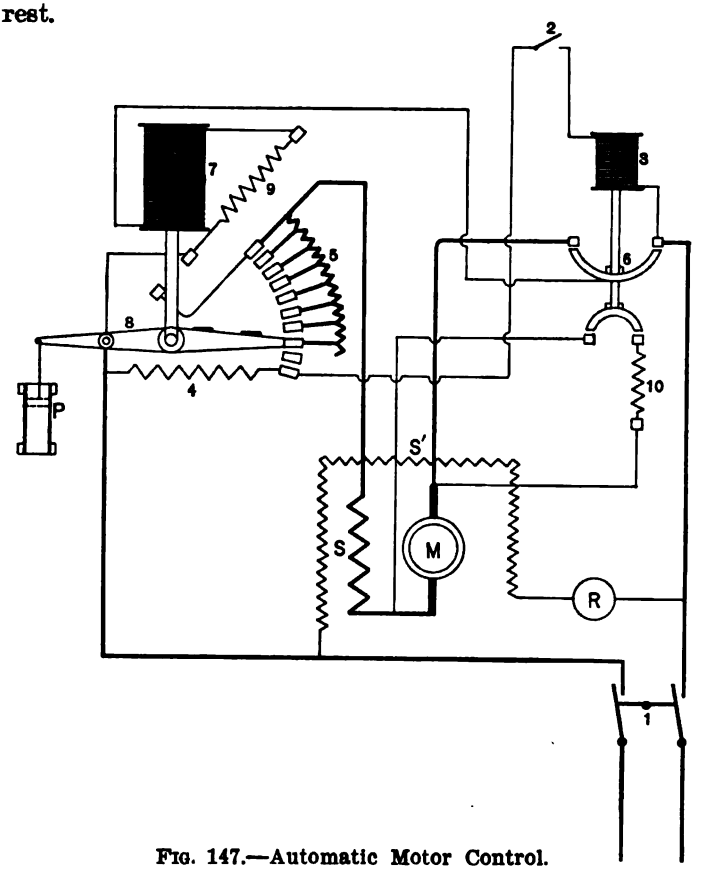


FIG. 147.—Automatic Motor Control.

Water-Tight Flame-Proof Panels.—Water-tight flame-proof panels are used in locations greatly exposed to moisture and where powder is handled as in handling-rooms, magazine passages, etc. Navy standard specifications require that in general they consist of a cast metal water-tight flame-proof case containing the necessary resistances, connections, and operating parts which are controlled from without by means of rods or levers passing through approved stuffing boxes.

The panels contain the following parts: resistances, circuit breaker or overload release, no-voltage release, reversing switch (if required), starting arm and contacts, and necessary field contacts when necessary for variable speed motors.

In this panel, the automatic overload release is in the nature of an ordinary spring-operated circuit breaker having the release mechanism operated by a positive hammer blow, and should open the circuit in case of overload under any condition. The overload device must be such that it will not operate by short-circuiting or opening the circuit of the retaining magnet of the no-voltage release, and must be provided with renewable arcing contacts of carbon.

Controllers.

A controller is an arrangement for making the proper electrical connections between the main supply lines and a motor, so as to control the direction and speed of rotation. It is used for the control of heavy currents in motors of above 10 horsepower and finds extensive use in such equipments as turret turning, gun elevating, rammers, ammunition hoists, boat cranes, deck winches, and in service generally where there is required continuous starting and stopping, and changes of direction and speed.

A typical controller is shown in Fig. 148. It consists essentially of the following parts:

The *frame with cover; cylinder* or *cylinders; contact fingers; blow-out magnet; arc deflector; star-wheel, cap-plate,* and *handle.*

Frame.—The frame is of cast iron provided with a removable cover, in most cases made of sheet iron, but in some cases made of brass.

Cylinder.—The cylinder is supported in bearings in the frame, and is operated by means of a suitable handle. On this cylinder are carried contacts suitably insulated from the shaft and from each other, arranged to make the necessary combinations for the control of the motor. The outside surface of these contacts is cylindrical and extends through only a portion of the circumference. In the center of this cylinder is a shaft which serves the purpose of supporting and operating the cylinder and also serves

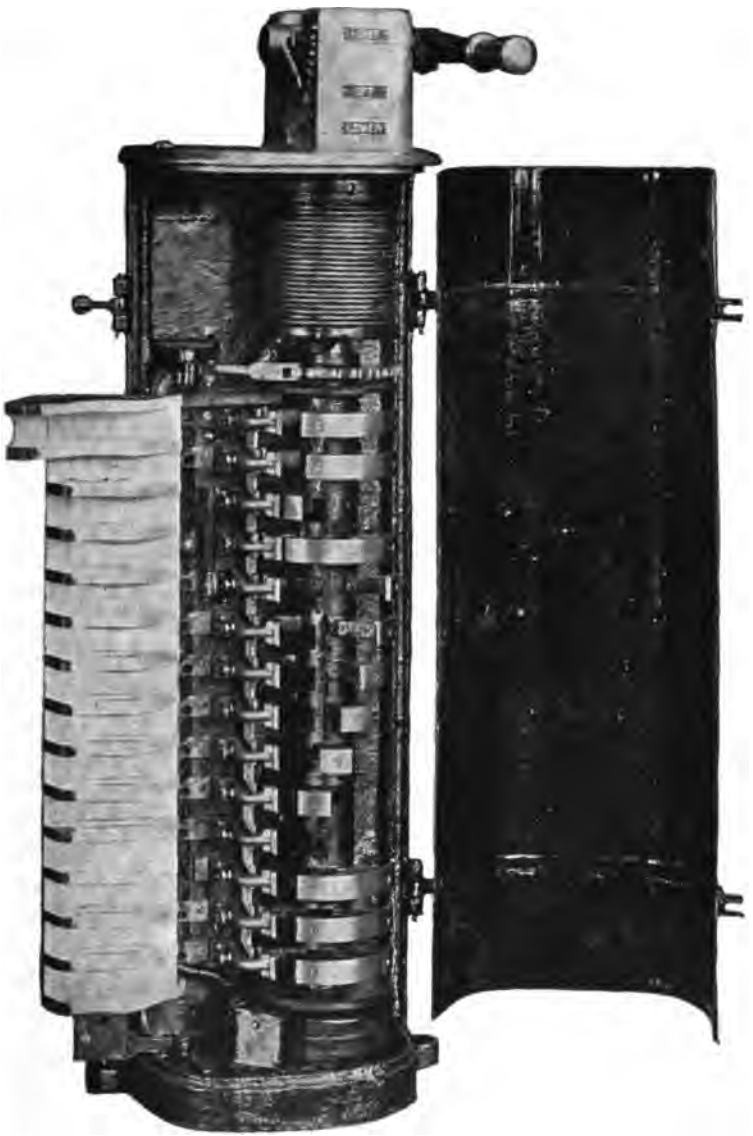


FIG. 148.—B-28 E Controller. Gen. Elec. Co.

as a part of the magnetic circuit afterwards described. Upon this steel shaft is supported, either a wooden cylinder or a cylinder of specially made composition. On the outside of this are held castings made of brass, which, in the case of the wooden cylinder, are fastened by means of screws, and in the case of the composition cylinder they consist of hollow cylinders entirely surrounding the special insulating composition, which by application of heat has been made to firmly fill the interior of the hollow cylinder and secure it to the shaft. In most cases, all those contacts which are to be electrically connected, are made in one casting, there being, consequently, a less number of castings on the cylinder than there are contacts. The projections on this casting, after being turned to a true cylindrical surface, are supplied with copper contact rings generally about 1 inch in width and $\frac{1}{4}$ inch in thickness, which have been shaped to a true cylindrical form, and are fastened to the projections by means of two or more screws. These contact rings are thus made removable, so that in case of burning or of any injury to them, they may be replaced by new ones.

Contact Fingers.—On the wooden block supported by the frame are several contact fingers, insulated by the block from each other, and from the frame. These fingers are stamped from copper, and are held in position by springs and adjusting screws, so that when the cylinder is rotated its contact rings will make firm contact with the fingers, the springs of which give sufficient pressure to insure a good electrical connection. The contact fingers are supplied with binding posts in which wires or cables are fastened, making the necessary connections between the line switch, motor, rheostat, and solenoid brake if used. In some cases these wires are carried directly out through the back of the frame, being insulated from it by rubber bushings, and in other cases the leads are carried down inside of the frame and brought out through a hole in the bottom. The fingers are fastened to their bases by means of small screws which readily permit of replacing any which may be injured. The adjusting screw is provided with a check nut, so that the screw will not jar loose, after the finger has once been adjusted. The finger bases are fastened to the wooden block by means of screws and the wooden block is fastened to the controller frame in a similar way.

Blow-Out Magnet.—In order to reduce the burning of the contacts which would naturally result to some extent from the operation of the controller, a magnetic circuit is provided which has the effect of instantly breaking the electric arc formed when any circuit is broken. This circuit is produced by means of a spool or coil surrounding the lower end of the cylinder shaft. In addition a steel pole piece is supported over the fingers, being connected magnetically at the bottom of the shaft, so that a magnetic circuit is formed, consisting of the shaft, bottom of controller frame, and pole piece, the circuit being completed by the air space between the pole piece and the shaft, forming a magnetic field along the ends of the fingers. There is, of course, some magnetic field on the other side of the controller cylinder, between it and the back of the controller, but only that portion formed between the pole piece and the shaft is used in blowing out the arc.

In some controllers, the magnetic blow-out spool does not surround the cylinder shaft, but has a separate core cast to the back of the controller, to which is attached a pole piece covering the contact fingers. In this case the magnetic field is produced between the pole piece and the back of the controller, the cylinder being in this field, and concentrating the magnetism on a line between the pole piece and the shaft, which line is near the ends of the contact fingers.

In other controllers, the magnetic blow-out spool is a long narrow coil surrounding the tip of the pole piece and carried just over the line of the fingers. This serves to concentrate the magnetism along the line of the finger ends where the arcing takes place. In the connections of the controller the winding of this spool is in series with the armature of the motor, so that whatever current passes through the armature also passes through the blow-out coil, and produces the necessary magnetism, which is therefore approximately proportional to the amount of the current used.

Arc Deflector.—In order to more thoroughly insulate the fingers from each other and from the cylinder and pole piece, strips of fire-proof insulating material are provided extending between the fingers and pole piece, with division plates extending from this plate between the fingers themselves and in some cases an addi-

tional plate is provided between the finger bases and the cylinder. These insulating pieces prevent the arc, when thus formed, from being blown from one finger to the next, thus making a short circuit, which might otherwise occur and thus impair the effectiveness of the controller.

Star-Wheel.—In order that the operator may judge of the position of the cylinder while operating it, without looking at it, a wheel is fastened to the cylinder shaft containing several notches or teeth, which engage a roller, supported on the end of the pawl which is pressed against the star-wheel by means of a spring. As the cylinder is rotated this pawl offers some resistance to the movement of the handle, and as it moves into the notches the effect is plainly felt by the operator, who should leave the controller handle only in the position shown by this pawl and star-wheel, because it is at these points that the fingers make the best contact with the cylinder. It should not be left at intermediate points. Also the star-wheel gives the additional advantage of making a quick break at the time of passing from one position to another, as the tension of the spring helps turn the cylinder after the roller has passed the point between two notches.

Cap-Plate.—At the top of the controller is a cap-plate containing stops to limit the motion of the handle and points to show the position of the cylinder. In some places this cap-plate is made of brass, in order not to interfere with the magnetic circuit and in other cases merely to form a more finished appearance. On some controllers the cap-plate is provided with a notch into which a latch on the handle will fall when the cylinder is turned to the off position, so that the operator when quickly stopping a motor will not carry the handle past the off position and reverse the motor.

Handle.—The handle consists of a brass lever having a hole in its hub, made to fit the end of the shaft and allowing it to be easily removed, and carrying at its outer end a wooden revolving piece making it more convenient to operate. On some controllers a thumb-latch is attached to the lever, which is controlled by a pin passing through the center of the wooden piece, allowing the latch to be released by pressing on the pin. The latch is pressed down by a spring so as to engage the notch on the cap-plate when turned to the off position.

This particular type shows the cylinder to be operated by the meshing of gear wheels, the smaller of which is turned by an operating wheel on top of the controller.

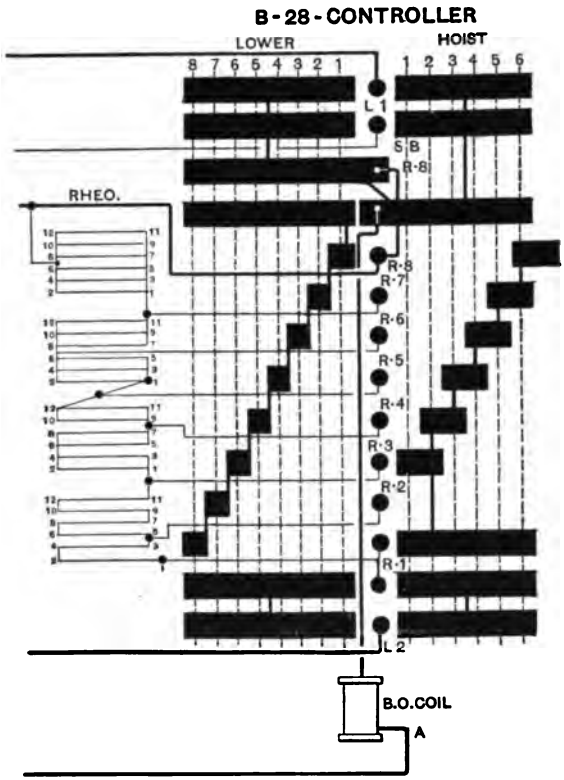


FIG. 149.—Developed Controller.

Developed Controllers.

In order to more clearly understand the diagrams of connections to be given under the application of motors, a so-called developed controller is shown in Fig. 149.

This shows the development of the circular contact rings on a plane surface, with the indication of the contact fingers and method of connecting the resistances of the rheostat.

All black lines and surfaces are conductors, the contact rings being indicated by the broad heavy lines and the contact fingers by circles. Where small white circles are shown on a black background, they indicate contact fingers resting on the contact rings.

It must be remembered that all contact fingers are stationary while the contacts are moved by the motion of the cylinder. In the above illustration a clockwise motion of the handle would result in *all* the contact rings to the right of the row of fingers moving to the left as there viewed, and all the others on the other side moving to the left. A contrary motion of the cylinder would produce opposite motion of the contact rings.

Contact is made between finger and ring when the ring is moved so that the finger rests and presses firmly on it. Connectors connecting together contact rings move with them.

Classes of Controllers.

There are three general classes of controllers designed according to the kind of work they are to perform. Those made by the General Electric Company, which finds almost universal use on shipboard are arbitrarily designated as the R, B, and P types.

R Controllers.—The R controllers are **rheostatic** in their method of operation, and are used for the purpose of starting, stopping, reversing and controlling the speed of motors. They are particularly adapted for motors designed to carry a load in either direction. In this type of controller the combinations are such that when the cylinder is turned to the first position in one direction, the circuit contact rings on the cylinder make connection with corresponding contact fingers, connecting the motor armature and field to the line, and having in its circuit the rheostat connected to the controller. On further rotation of the cylinder, the rheostat is gradually short-circuited, until at the last position of the cylinder the rheostat is entirely out of circuit, the motor then attaining its maximum speed. On returning the handle to its original position, this rheostat is again introduced into the circuit, and the motor slowed down and stopped. When the cylinder is turned in the opposite direction, the same effect is produced with the rheostat, but the direction of current through the armature, but not through the field, is reversed.

A developed form of a typical R controller is shown in Fig. 150 used on turret gun rammers and formerly used for gun elevating. The motor is a series motor, the lower two lines on the left are the armature leads and the upper two are the series field leads. It will be seen how the controller connects them in series.

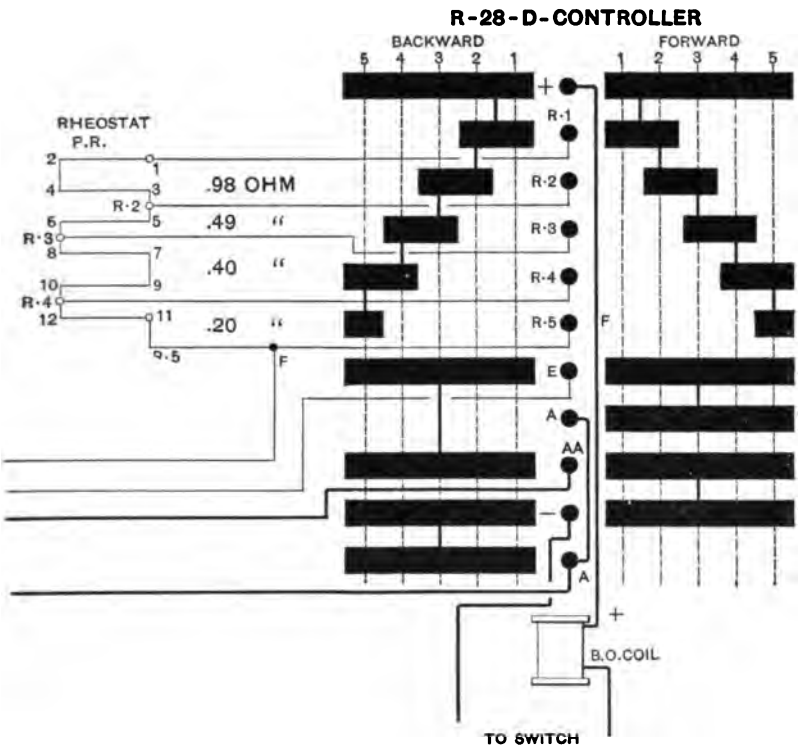


FIG. 150.—R-28 Controller. (Developed.) Gen. Elec. Co.

B Controllers.—The B controllers are those which are designed to give **electrical braking.** By this the electrical solenoid brake used in some cases is not meant, as that is simply a mechanical brake electrically operated. But in the B controller the motor is made to run as a generator by the momentum of its armature or load, and in this way reduces its speed or stops itself. There are two kinds of

B controllers; in one kind the various combinations are made on a single cylinder, while in the other kind, the braking effect is obtained by means of a second cylinder independently operated. In both kinds of these controllers the contacts are arranged so that in hoisting a load the operation is exactly the same as on one side of the R controllers, but on acting as a brake controller for lowering a load, or for carrying very light loads, a different combination is made, so that the rheostat to which the controller is connected, instead of being in series with the armature and gradually short-circuited as the armature is brought up to speed, is connected across the line in shunt with the armature.

This controller is built to put in operation the Day system of control as further described under Motor Control in a previous chapter.

A developed form is previously shown in Fig. 149.

P Controllers.—This type of controller is used where the **voltage of the generator is to be varied in order to obtain a change of speed of the motor.** It is radically different from other controllers both in design and in system of control, although it retains the general features of all controllers, but the proportion and arrangement of its contacts are quite different. In its method of operation it introduces resistance into the field circuit of the generator in order to vary the voltage at the motor armature. The fields of both generator and motor are separately excited, and the brushes of the generator directly connected to the brushes of the motor through the reversing contacts on the controller cylinder. Under these conditions a variation in the field of excitation of the generator produces immediate change in the voltage impressed on the motor armature and a consequent change in the speed of the motor.

The motor is reversed by turning the controller handle in the opposite direction from the off position, the contacts on the controller cylinder being so arranged that resistance in the generator field circuit is varied the same as before, but the direction of the current through the armature is reversed, thus reversing the direction of rotation. At the off position the armature is short-circuited through a resistance, causing it to act as a generator and generate current and thus absorb energy. This produces a powerful braking

effect and brings the armature to a quick stop. The suddenness of the stop may be regulated by adjusting the resistance thus introduced into the armature circuit.

The P type of controller is used for turret control, both under the original Ward-Leonard system, in which the field of the main ship's generator was controlled, later in the motor generator system, in which the generator field of the motor generator was controlled, and still later in the rotary compensator system in which the fields of two machines are controlled. All these systems will be described later.

The electrical connections of a controller of this type will be described later under Motor Applications.

Circuit Breakers.

General Description of Circuit Breakers.—The automatic circuit breaker is a device for automatically opening a circuit when the current exceeds the maximum amount desired. It is ordinarily adjusted by means of a spiral spring, the tension of which may be varied; the current at which the circuit will be opened being indicated on a scale near the spring.

The point at which the circuit breaker is opened is located in such a position that the arc is easily destroyed and any damage caused by the arc may be repaired by replacing the injured parts. In other words, a circuit breaker is simply a switch which, when released by an electrically controlled latch, is thrown open by a spring. The essential parts of the circuit breaker consist of the arc-rupturing device, the main contacts, the resetting device and the adjusting and tripping device.

Circuit breakers in general are of two kinds, depending upon the method employed for rupturing the arc. They are:

1. **Magnetic blow-out,** in which the arc is extinguished by a strong magnetic field.

2. **Carbon break,** in which the arc is ruptured at a secondary set of carbon contacts, which may be easily renewed.

Magnetic Blow-Out Circuit Breakers.—Magnetic blow-out circuit breakers, made by the General Electric Company, are known as Type M., Form Q., and Type M., Form L., the difference between

them being in matters of design and not in the principle of operation. They are single-pole instruments.

The different sizes of these circuit breakers are distinguished by their carrying capacity rating, such as M. Q. 100/175. The first number of the rating is the minimum current that will automatically open the breaker, and the second is the maximum continuous carrying capacity, but the breaker may be set to open at 50 per cent above this. This rating may be based on the continuous carrying capacity or the intermittent carrying capacity of the circuit breaker.

Carbon Break Circuit Breakers.—The carbon break circuit breaker, known as Type C., Form D., is a double-pole instrument consisting of two single-pole automatic switches mounted on one base. These may be set separately, but should both release together. The special advantage which this type has over the single-pole circuit breaker is that the switches may be independently closed and a short circuit or overload, which may develop when the last one is thrown in, will open the first one and protect the circuit.

The different sizes of these circuit breakers are distinguished by their carrying capacity rating, as already described for the magnetic blow-out circuit breakers.

M. Q. Circuit Breaker.—The M. Q. circuit breaker is shown in Fig. 151. The contacts at which the circuit is made or broken are located at the upper part of the base, where they are enclosed by two iron plates which form the poles of a powerful electromagnet in series with the line situated at the lower left-hand corner. The contacts themselves are composed of two flexibly mounted fingers on each side of the break, and are connected, when the circuit breaker is set, by a copper segment which revolves around the central pivot, forming a wiping contact with them.

Above these contacts there is a rectangular fiber box, open at the top and bottom, in which the arc is broken. There is one metal-burning block above and connected to each pair of fingers, to which the arc is transferred as soon as formed, thus preventing the fingers from being burned and so disabled for further use. These burning blocks are renewable.

The arc which is formed when the circuit breaker opens is located

FIG. 151.—M. Q. Circuit Breaker. Gen. Elec. Co.

in a strong magnetic field, which compels it to elongate towards the top opening until it is ruptured.

The re-setting device consists of a handle projecting towards the lower right-hand corner, which is thrown off by a spiral spring at the center, and which, when forced in position by hand, is locked by a latch operated by a tripping device.

The tripping device consists of a swinging armature held away from the pole of the magnet by a spiral spring, the tension of which may be adjusted to allow the circuit breaker to open at the desired current. When the magnet becomes strong enough to attract this armature against the tension of the spring, the latch releases and the circuit breaker opens. The circuit breaker may be tripped by hand by forcing the armature towards the pole piece.

In order to inspect the contacts, the front pole piece may be removed by taking off the hexagonal nuts holding it. The front of the insulation box below may also be removed, leaving all the working parts exposed for examination or repair. The illustration given shows the parts removed.

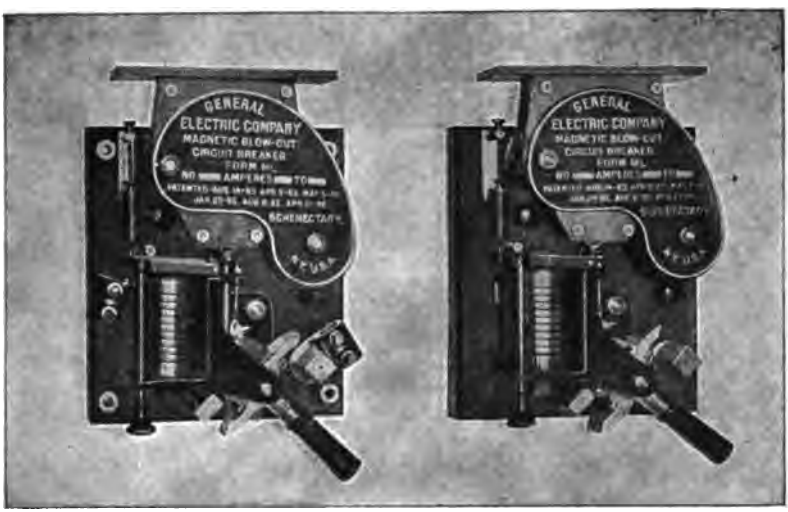
M. L. Circuit Breaker.—The M. L. circuit breaker is like the M. Q. a single-pole instrument. This type of circuit breaker is shown in Fig. 152. It is made with two coils, one of which furnishes a means of automatically tripping the breaker on overload, the other furnishes the magnetic field to blow out the arc. When the circuit breaker is closed, these two coils are connected in multiple, but in opening, as soon as the laminated brushes are out of contact with the contact studs, the blow-out coil only is in circuit and a very strong magnetic field is produced which blows out the arc formed at the secondary contacts and opens the circuit.

The main contact consists of an S-shaped set of copper leaf contacts which complete the circuit when closed against the contact studs at the lower right-hand corner of the base. A secondary set of contacts in multiple with the above is located in the strong magnetic field formed by the blow-out coil.

The secondary contacts consist of two fixed contacts, located in the fiber box or chute in which the arc is broken and between the poles of the blow-out magnet, and a movable contact, carried on the end of a rod and forced up from below to close the space between

the fixed contacts. These secondary contacts are renewable and should be carefully attended to in order to assure their being in good condition, as poor secondary contacts will cause the main laminated brush to be destroyed.

When an arc is formed at the secondary contacts the strong magnetic field causes it to elongate towards the top opening of the fiber chute until it is ruptured.



FRONT CONNECTED. BACK CONNECTED.

FIG. 152.—Form M. L. Magnetic Blow-Out Circuit Breakers. Gen. Elec. Co.

The re-setting device consists of the handle projecting towards the lower right-hand corner, which is thrown off by a spiral spring at the center and which, when forced in position by hand, closes first the secondary contacts by forcing upward the rod which carries the moving contact, then the main S-shaped brush contacts, and is locked in position by a latch operated by a tripping device.

The tripping device consists of a swinging armature pivoted over the pole of the tripping magnet located at the lower left-hand corner. It is held away from the pole of the magnet by a spiral

spring, the tension of which may be adjusted to allow the circuit breaker to open at the desired current. When the magnet becomes strong enough to attract this armature against the tension of the spring, the latch releases and the circuit breaker opens. The circuit breaker can be operated by hand by pulling down on the rod connected to the armature. It is calibrated by screwing up the calibrating screw until the disc near the spring is opposite the desired mark on the scale.

FIG. 153.—Type "C", Form K, Carbon Break Circuit Breakers, 250 Volts, 1000 Amps. Closed. Gen. Elec. Co.

Type "C" Circuit Breakers.—The type "C" circuit breaker, so called because the arc is ruptured by carbon auxiliary contacts, is shown in Fig. 153, and consists of two stationary contacts with a laminated brush, and secondary copper, and tertiary carbon contact which will close by means of a handle operating through a toggle joint.

It is held closed by a latch which is tripped by an armature, the latter being when the current exceeds a predetermined amount.

This breaker is made single or double pole, that shown in the figure being single pole.

In the smaller sizes, a coil is employed to carry the current for moving the tripping armature, while in the larger size, such as is shown in the print, the armature simply forms a swinging section of the magnetic circuit, the stud passing through this circuit and forming a tripping coil of one turn only.

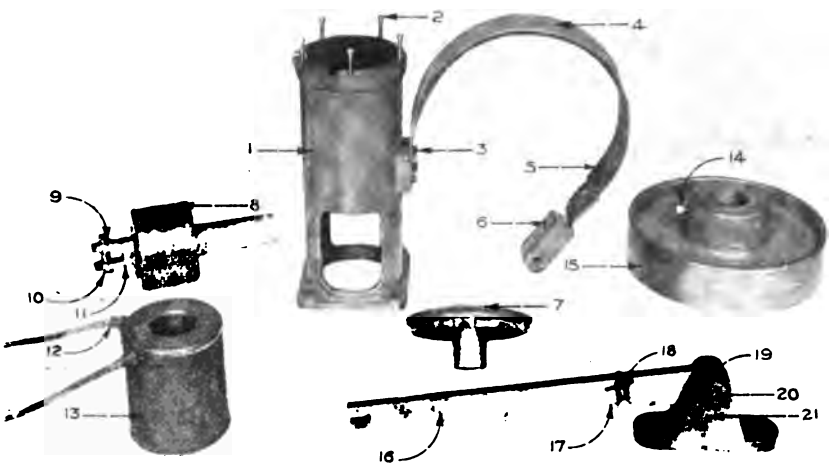


FIG. 154.—CB-17 Motor. Gen. Elec. Co. Detailed Parts of Band Brake.

Solenoid Brakes.

These are used on motors particularly designed for hoisting and lowering weights and are intended to check the speed or even stop the motor and hold the load in case of failure of current, and to prevent the load from falling and running the motor as a generator.

They are used on all turret ammunition hoists, on chain ammunition hoists, on whip hoists, boat cranes, and deck winches.

The solenoid brake is made in two types:

1. An electrically-operated **band** brake.
2. An electrically-operated **friction disc** brake.

The former type is fitted to chain ammunition hoists, and with a modification to deck winches and the latter, with modifications, to the other form of hoists.

The Solenoid Band Brake.—The band-brake type consists essentially of the following parts: wheel, band, solenoid, and lever, and is shown in detail in Fig. 154. The wheel is a flat-faced pulley located on the armature shaft. The brake band consists of sheet steel lined with leather and surrounds the wheel, one end being attached to a lever near the end upon which it pivots, and the other end of the band secures to the outside of the solenoid case. On the free end of the lever is attached the solenoid plunger which

FIG. 155.—Assembled Solenoid Band Brake. Gen. Elec. Co.

ordinarily acts under gravity, thus drawing the band tightly around the wheel and preventing the armature from turning. When this weight is lifted the band is released and the wheel turns freely.

The solenoid consists of a spool the core of which is attached to the brake lever and lifts the same when energized. Consequently, when a current is passing through the coils, due to the operation of the controller, the brake is automatically released and remains open until the circuit is broken.

The brake should always be kept free to move, as it is the ultimate safety device in case other means of control fail.

The wheel should be kept clean and free from oil or dirt, the leather on the band in good condition, and the band adjusted so that it does not bear upon any point of the wheel when lifted.

The connection of the solenoid should be examined whenever the condition of the motors is inspected.

An assembled solenoid band brake fitted to an armature shaft is shown in Fig. 155.

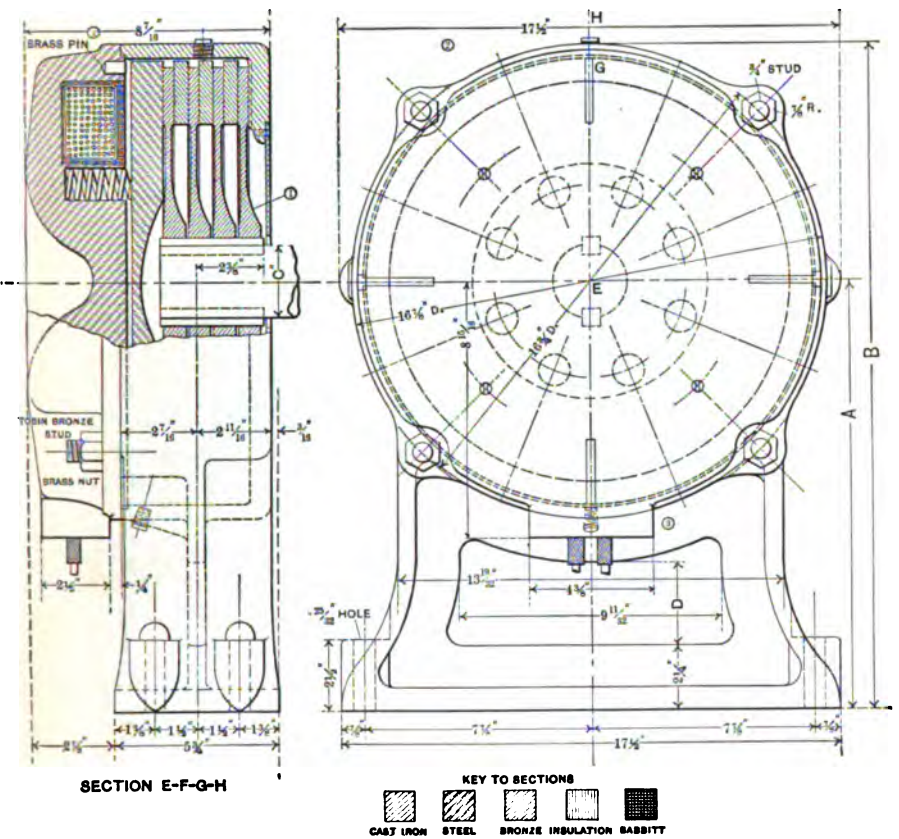


FIG. 156.—ED-108, Form A Disk Brake. Gen. Elec. Co.

The Disc Brake.—The automatic disc brake shown in section in Fig. 156 and in exploded view in Fig. 157 consists of a cast-steel frame, an electromagnet, steel armature, discs, annular rings and springs.

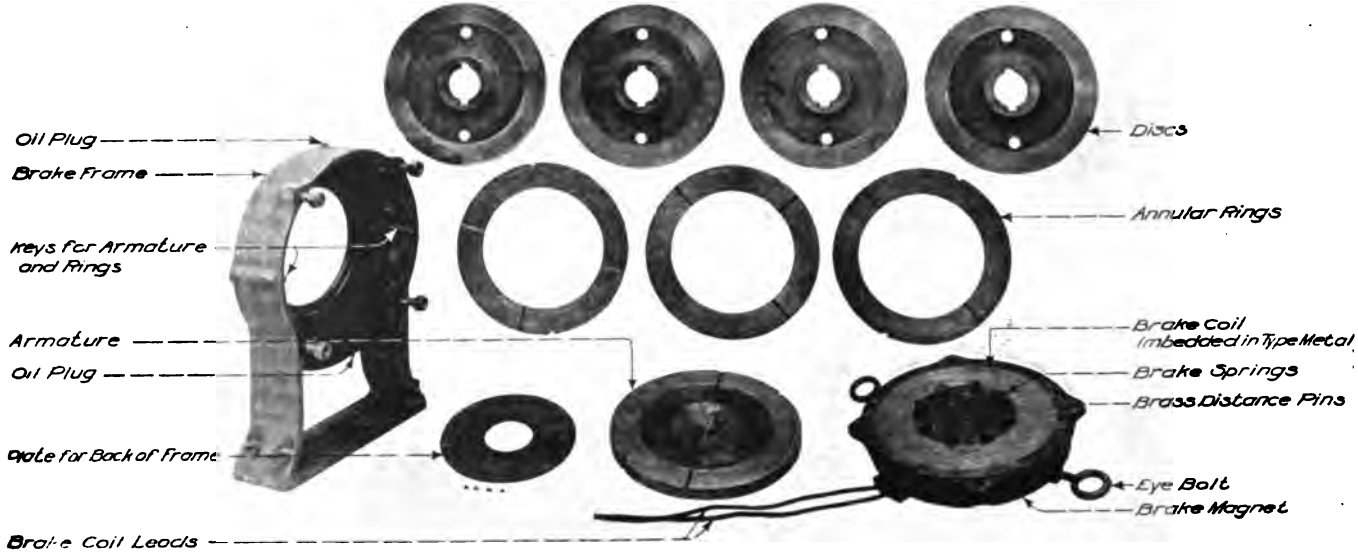


FIG. 157.—ED-108 Disc Brake. Exploded View.

Frame.—The frame is a steel casting consisting of a base carrying a barrel of sufficient depth to receive the discs, rings and armature. Four tobin bronze studs provide a support for the electromagnet and there are two keyways diametrically opposite to receive the steel keys on which annular rings have an easy sliding fit. A hole is cast in the back of this barrel through which the extended motor armature shaft projects.

Electromagnet.—The electromagnet is a steel casting with suitable lugs which support it on the frame. Brass nuts draw the magnet to the frame, making a water-tight joint.

A coil slot, annular in form, is provided in the casting in which the winding is secured by type metal.

Suitable spring pockets equally spaced are drilled to receive the helical compression springs.

Armature.—The armature is a steel disc of a sufficient cross-section to carry the magnetic flux without excessive leakage. Four tobin bronze pins are tapped into the armature and project into recesses in the magnet. This construction keeps the armature from rotating while permitting easy motion parallel with the motor shaft.

Annular Rings.—The rings are of cast iron and have a sliding fit on the keys in the frame, which prevent their rotation.

The outside diameter of the rings is slightly less than the inside of the barrel. The inside diameter is carried out to a point where the friction is most advantageous and yet provides a sufficient cross-section to insure against an excessive wear or heating.

Suitable oil slots are provided to secure a uniform lubrication.

Discs.—The discs are of bronze and have suitable hubs which are keyed to the motor shaft.

These discs have an easy motion parallel with the shaft but being keyed thereto must revolve with it.

Holes in the discs relieve atmospheric pressure and add to the convenience of removing the discs from the shaft.

The outside diameter of the discs is slightly less than the rings, to secure a clearance from the keys in the frame. The width of the friction face is thus the difference in radius between the outside of the disc and the inside of the ring.

Compression Springs.—The springs are helical in form and are wound of the best spring steel, copper plated. They resist the maximum compression without permanent set or injury.

Coil.—The winding consists of insulated copper wire, form wound, and wrapped with four thicknesses of varnished cambric and two thicknesses of linen binding.

The ends of the coil are soldered to terminals located in a water-tight connection box in the magnet, tapped for conduit, through which the brake leads are to be taken to the coil terminals.

The inside back of the frame is finished to a suitable diameter and thus becomes a friction face. Adjacent to it is a bronze disc keyed to the armature shaft, then an annular ring keyed to the frame, then another disc keyed to the armature shaft and thus throughout the series. Each ring is keyed to the frame and its adjacent disc to the motor shaft.

The electrical connections are so arranged in the controller that the motor circuits are simultaneously made with the brake coil circuit.

Thus when the controller is thrown on the first position the brake coil energizes the magnet, which draws the steel armature disc toward it, at the same time compressing the helical springs. Thus all pressure on the friction faces of the discs is relieved and the motor starts readily.

There is a sufficient clearance provided between each set of friction faces to reduce the running friction in the brake to a minimum, a lubrication of these surfaces is provided by an oil hole in the top of the frame and a drain hole in the bottom which permits a change of oil. Best operation is obtained with a minimum amount of lubrication.

When the controller is turned to the "off" position the brake coil circuit is opened and the springs immediately force the armature disc against the bronze disc keyed to the shaft and thus the pressure is transmitted to all the friction faces. Thus in coming to rest the armature shaft must carry the discs keyed to it through the friction of all the rings keyed to the frame, the friction face of the frame itself and the friction face of the brake armature. The spring pressure is sufficient to bring the motor armature quickly to a state of rest and yet not injure the friction faces of the discs or rings.

These brakes are designed to hold the load of the 12-inch ammunition hoists plus 25 per cent.

Magnetic Core Brake Type.—This brake consists of a disc, the periphery of which is a conical surface, and a stationary frame with conical recess within which the disc revolves with the conical surfaces in close proximity. Spiral springs force the conical surfaces together, and a coil winding imbedded in the stationary frame opposes the action of the springs and releases the brake when current is on the coil. The disc is loosely keyed to the shaft extension so that it is free to move lengthwise of the shaft thus allowing the brake to be set and released without interfering with the end play of the shaft.

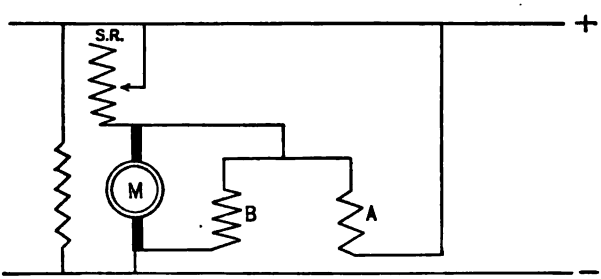


FIG. 158.—Brake Coil Connections for Hoisting.

The coil consists of two separate windings in parallel. These coils are connected up so that one coil is short-circuited when the armature receives full voltage. This gives a strong pull for releasing the brake and cuts down the current through the brake coils one-half under running conditions.

Brake Windings.—The connections of the brake winding are made so that in hoisting one coil is in parallel with the starting resistance and the other in parallel with the armature as shown in Fig. 158.

On starting the motor *M* for hoisting, as current is switched to the starting resistance *SR*, there is a greater difference of potential between the ends of this resistance than between the armature terminals, as the armature has not started to turn, so consequently coil *A* receives most of the current, while *B* is practically short-circuited by the armature. Coil *A* lifts the plunger of the solenoid

and opens the brake, bringing the core of the plunger and the solenoid yoke close together.

As the motor armature attains speed, and develops counter E. M. F., the difference of potential between its terminals becomes greater than that of the terminals of the starting resistance and coil *A*, so the current in *B* gradually increases while that in *A* decreases, and at full speed as the armature terminals have practically the full voltage of the line, *B* is fully energized while *A* is short-circuited, and *B* is now holding the brake open. This arrangement cuts down the current to that required to operate the brake through coil *B*, which is considerably less than the energy required for two such coils in series.

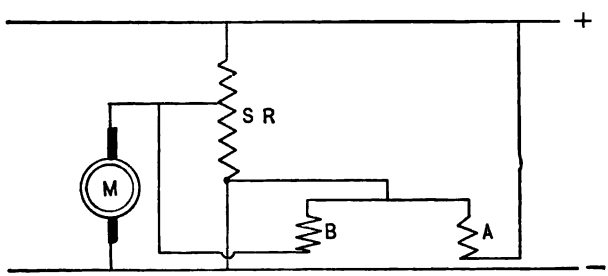


FIG. 159.—Brake Coil Connections for Lowering.

For lowering the connection is made as shown in Fig. 159.

On starting the motor for lowering, coil *A* is energized as before for hoisting, and remains so, the circuit being established to the — main by the connecting conductor from the starting resistance. As the armature current is now reversed, the current through *B* is also reversed, this tending to demagnetize the solenoid, working against *A*. Current through *B* increases as the counter E. M. F. increases, and if the coils had the same number of turns, one might neutralize the other, but coil *B* is made of smaller wire, so has less magnetizing power and coil *A* has still enough magnetism to hold the brake clear.

If the motor acts as a generator, the E. M. F. generated causes current through *B* which holds the brake released, but as it slows down, the current becomes less and less and finally the brake is set by the action of the opposing springs.

CHAPTER XVIII.

APPLICATION OF MOTORS.

Turret-Turning Equipment.

Up to the present time there have been four different systems used to electrically control the turning of turrets of our ships of war. These are generally referred to as the Ward-Leonard System, Motor Generator System, Rotary Compensator System and Variable Speed System.

Ward-Leonard System.

Principles of Operation.—The turret is turned electrically, the method of the speed control of the driving motors being especially adapted for fine regulation.

There are ordinarily two electric motors. These motors are governed in speed and direction by a controller, situated under the sighting hood. The operator has only to turn his controller handle from the "off" position in a clockwise or a counter clockwise direction accordingly as he wishes the turret to move, and the motors will drive the turret as desired, the speed of travel being dependent upon the amount which the handle has been displaced.

The method of control depends upon the fact that *the speed of a motor armature running in a constant magnetic field is proportional to the volts impressed upon its brushes.* Therefore, by conveniently varying this voltage the speed of the motor is changed.

By this method each turret requires one independent generator for the supply of the turning motors, but the switchboard is so designed that any of the several generators may be used for any turret.

The fields of the motors and of the generator are separately excited from the switchboard bus bars and are consequently independent of the voltage generated by the armature of the generator.

The field rheostat on the generator panel board is cut out and

in its place another rheostat in the turret operated by the controller is used, the generator field wires being carried to the turret for this purpose. The series coil of the generator is shunted by a switch, the object of this being to allow the series coil to have a slight effect in building up the voltage of the generator so that the turret may start more promptly than if it were dependent on the shunt coil alone.

The armature terminals of the generator are connected through the necessary switches, etc., directly to the armature terminals of the motors. The motors are usually in multiple. As the engine drives the generator armature at a constant speed the volts delivered by it to the motor armatures are approximately proportional to the shunt field excitation, and consequently the speed of these armatures, and of the turrets, is directly controlled by the operator in the turret.

This statement is correct, regardless of the mechanical resistances encountered, up to the load which causes the engine to slacken materially in speed.

The current required is dependent upon the turning moment necessary to overcome mechanical resistance, and will not vary greatly at any constant speed, regardless of what that speed may be.

The circuit is so arranged that either motor may be electrically cut out and the other motor be operated to the extent of its capacity.

If, when the turret is in motion, the controller is turned to such a position that the armatures would be driven as motors at a lower speed than that corresponding to the speed of the turret, the turret will drive the armatures, which will immediately generate current and absorb energy, bringing the turret down to the speed of the armatures when running as motors.

When the controller is placed on the off position, the brushes of the motors are connected through a low resistance, so that the armatures would generate large currents if revolved, thus requiring much expenditure of energy, which would be greatly increased by the mechanical connections from the turret, and thus electrically locks the turret. This condition does not hold unless the motor fields are excited.

The controller, in addition to operating the generator field rheostat, also sends the current to the motor armatures in the direction to give the rotation required.

There is an ammeter in each armature circuit, so that the operator may know when either motor is running under unusual load. An automatic circuit breaker opens the armature circuit of both motors in case of an overload.

The brushes of the motors and the generator are connected by the armature leads and are independent of all other connections.

The field of the generator is separately excited from the constant potential bus bars, and this circuit is extended to the rheostat located in the turret. The motor fields are also excited from these bus bars.

The reason for separately exciting the generator field is to cause it to respond immediately to a change of the rheostat and thus avoid the delay required in building up a self-exciting generator. The motor fields are separately excited in order to give a constant excitation, which could not be obtained from the driving generator, as the pressure at the motor brushes will vary according to the desired speed.

Thus the person operating the rheostat controls the speed of the motor, which will remain constant at any point until the resistance is changed.

In the actual installation the same hand wheel which controls the rheostat also controls the direction of rotation of motor, so that the operator who is training the turret has complete command of the direction and speed of movement.

Fig. 160 shows the entire connection of this system in which one main generator is used to turn a turret, as originally installed, and by the aid of the description of the electrical connections the different connections can be traced.

The controller used is of the P. type, mentioned under the head of Classes of Controllers, Chapter XVII.

Electrical Connections.—The electrical connections are shown on Fig. 160. The armature connections of the motors are brought to the fingers connected with the second wide segment from the bottom after having passed through the blow-out coil and the fingers

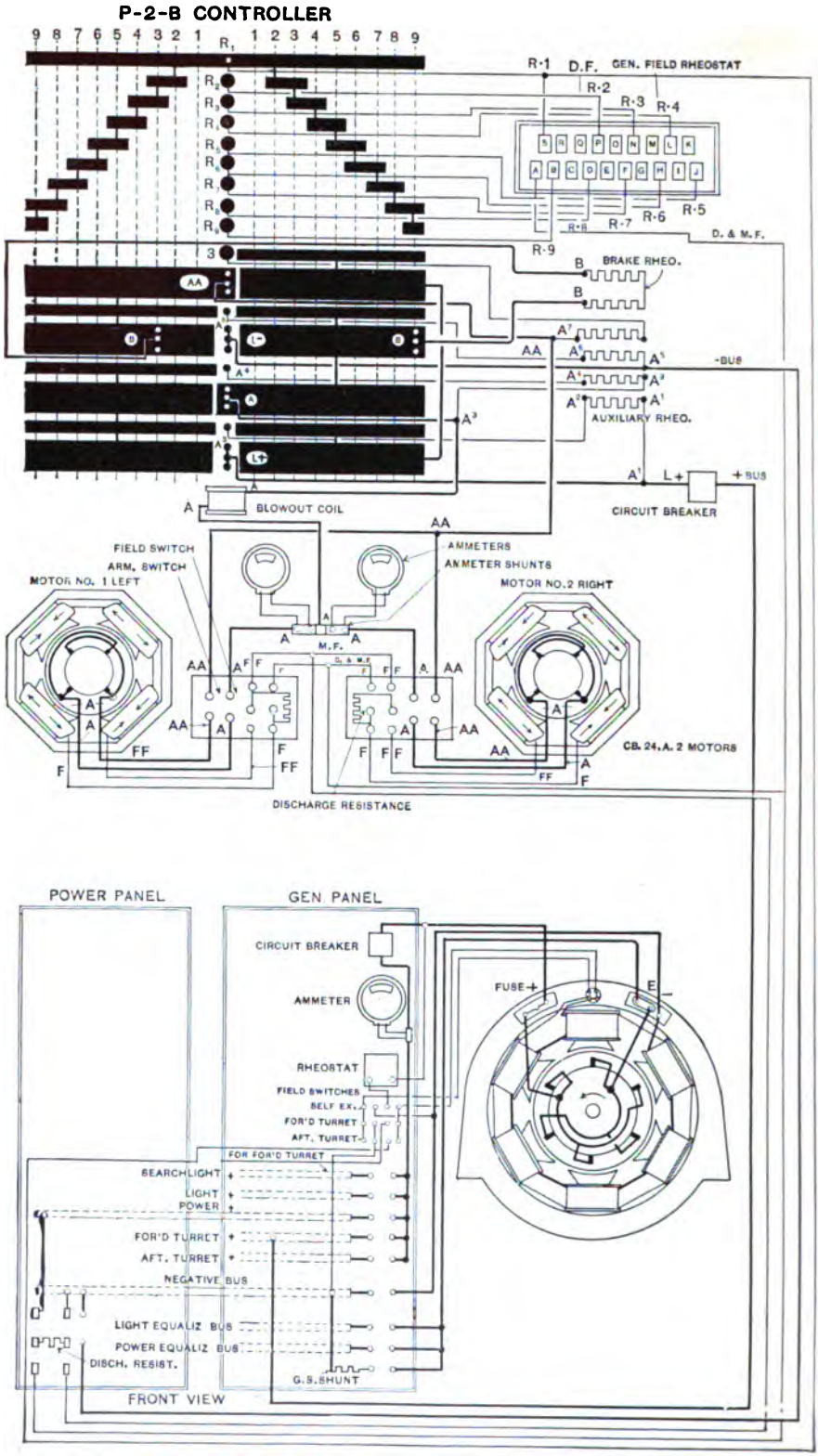


FIG. 160.—Electrical Connections of Ward-Leonard System.

connecting with the upper wide segment. The main lines are brought to the binding posts attached to the fingers of the two remaining wide segments. From each one of the main lines and armature leads, is branched a circuit through an auxiliary rheostat, and connected to the single fingers. It will be noted that the auxiliary contacts are longer than the main contacts, so that in rotating the cylinder in either direction from the off position, the auxiliary contacts touch their corresponding fingers a little before the main contacts make connection, and breaks the connection later when the controller is being turned off. This provides a gradual making and breaking of the main circuit in the operation of the controller, and reduces the amount of arcing that would occur at the main contacts if the auxiliary contacts were not used. When the cylinder rotates on the first position the main connections have been made and the current passes as follows: From the switchboard through the circuit breaker, to the lowest finger, to contact rings, to the lead to the motor armatures, through the switches and motor armatures, and back to the other side of the generator armature circuit through the second wide ring from the top. At this time the field of the generator is separately excited through the field rheostat which is connected to the controller, the leads of which are marked $R1$ to $R9$. While this rheostat is in the field circuit, the potential of the generator is at a minimum, but on turning the controller cylinder to the second position, the section $R1$ to $R2$ of the rheostat is short-circuited, the field current thereby increasing and the potential of the generator being raised, which, of course, increases the speed of the motors. The further rotation of the cylinder short circuits more of the field rheostats, until on the 9th or last position, the entire field rheostat is short-circuited, and the potential of the generator reaches its maximum. On returning the cylinder to the off position, the field rheostat is again connected in the field circuit, reducing the potential of the generator, and therefore the speed of the motor, until just before the off position is reached, the main contacts leave their fingers, thus forcing the current to go through the auxiliary rheostat, reducing the current considerably, and when the off position is reached, the two main lines are entirely disconnected from the motor armatures, the circuit of the armature

being closed through a brake rheostat by means of triple fingers on the back of the controller, this bringing the armatures to a sudden stop. The circuit is made as follows: Armature terminals to blow-out spool, to line ring, to left-hand brake fingers, to brake rheostat, to right-hand brake fingers, to other terminals of armature. The suddenness of the stop of the armature may be regulated by adjusting the brake rheostat. On turning the controller in the other direction from the off position, the same results are obtained except that the direction of current through the armature is reversed, thus reversing its direction of rotation.

Motors and Gearing.—In order to make the understanding of the turret-turning system complete the following description is given of the motor gearing by which the turret is revolved, and as a general guide to the construction of the gearing of all turrets.

There is one motor located on each side of the turret below the floor. They revolve in opposite directions, both driving through bevel gears to one shaft which runs across the turret. This shaft carries at each end a right-hand double-threaded worm, and each worm engages with a worm wheel at the top end of a vertical shaft. At the lower end of the vertical shaft of each of the worm wheels is a pinion which meshes with the circular rack inside of the barbette, thus driving the turret.

The worm wheels are connected to the vertical shafts by friction clutches which can be adjusted by nuts above to carry the desired load, but to slip if it be exceeded, in order to prevent damage to the driving mechanism due to an excessive overload such as would occur when firing one gun, or in the case of impact of a shell on the outside, tending to produce rotation independently of the motors.

These friction clutches consist of fifteen flat discs, alternately of brass and steel, the brass discs being loosely keyed to the outer case and the steel discs fastened to the inner case which carries the worm wheel in the same manner, these discs being pressed together by the action of ten helical springs. These springs are held in the outer casing of the vertical shaft, and their pressure is adjusted by sliding a covering casting along the shaft by means of a large recessed nut and check nut at the top.

The object of the cross shaft is to allow one motor to revolve the

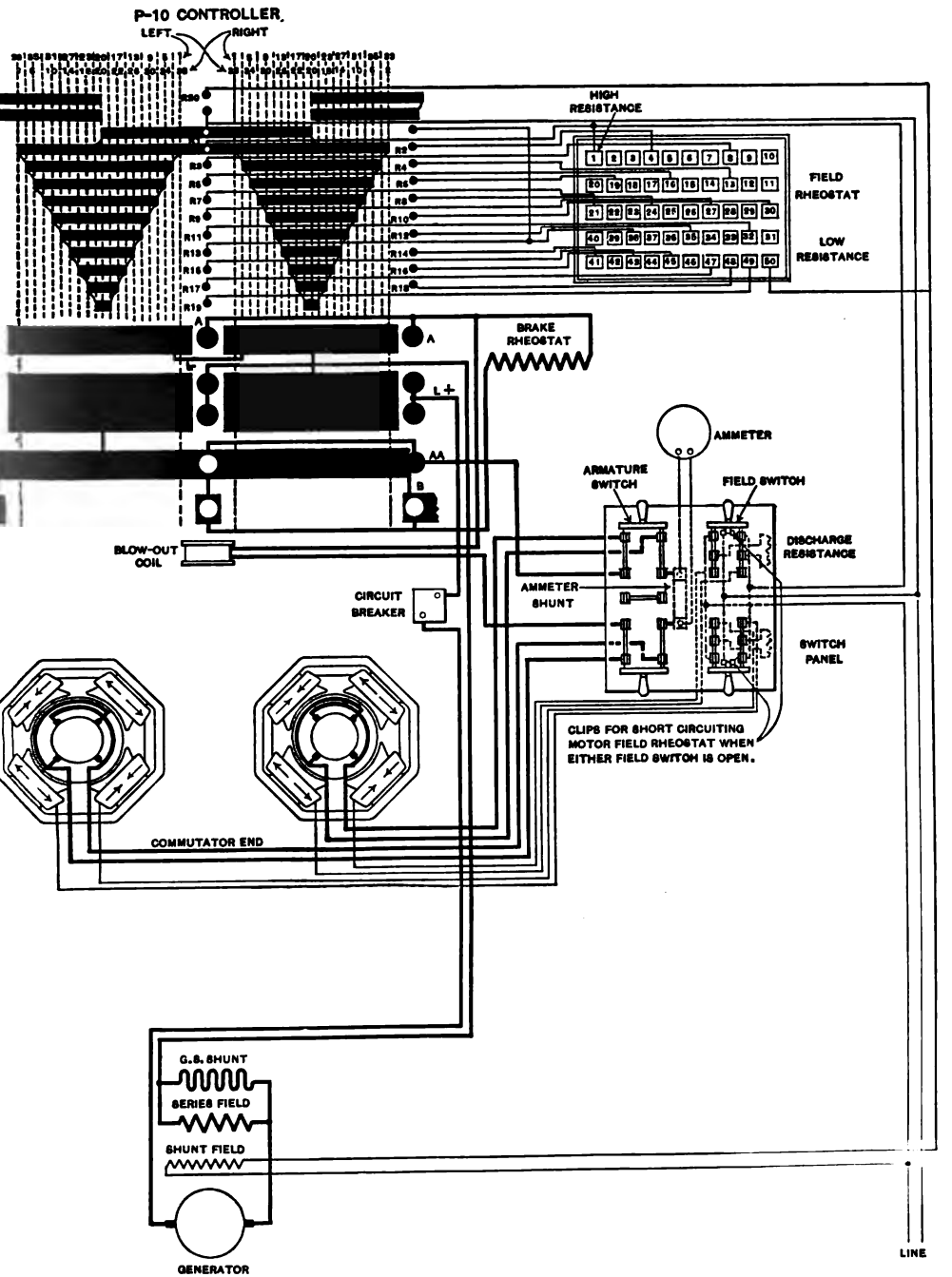


FIG. 161.—Variation of Ward-Leonard System.

turret by driving both pinions should the second motor be electrically or mechanically cut out, and also to permit one motor to revolve the armature of the other motor, in case the latter should fail electrically, through the bevel gears instead of through the worm wheel and worm, which would be the case if the cross shaft were not employed.

Connections of Generator, Motors and Controller for Turret-Turning System Using Combined Generator and Motor Field Control.

In the diagram of electrical connections shown in Fig. 160 the system of control embodies only variation of the field of the generator, but in that shown in Fig. 161, there is combined generator and motor field control. Another difference lies in the fact that in the first system the turning motors are in parallel while in that shown in Fig. 161 the motors are in series.

A form of controller used with this system of control is shown in Fig. 162.

Electrical Connections.—The function of the controller in connecting the current from the main generator to the armatures of the two motors in series is readily seen from the diagram of connections, the armature current in all cases being indicated by the heavy lines. The current through the armature motors is reversed by moving the contact pieces by the controller hand in opposite directions. It will also be noticed that the motor armature terminals are short-circuited through the brake rheostat when the controller is in the *off* position, so if the motors are given any motion independent of the generator current, they will act as generators, which, generating current through the low resistance will absorb power and bring them quickly to rest.

Current for the generator and motor fields is taken from power lines on the ship as indicated in the lower right-hand corner. This controller is designed to control both the current through the generator and motor fields, and the separate operation is as follows:

Generator Field.—Current flows from the left-hand line lead to and around the generator field, thence to the terminal on the controller resistance marked 50. Between each one of these numbered

blocks is a resistance. The current flows from block 50 through all the resistances to block 1, from there to the finger contact marked *R*1, thence to the contact ring over it and from there back to the line lead. This is the circuit in the *off* position and the generator field is excited when the line field switch is closed. As the controller is moved, say to the right, the contact ring on which rests *R*1, moves to the right and makes contact with *R*2. This results in short-circuiting the resistance from 4 to 1, and the total resistance in the generator field is reduced by that resistance. Further movement to the right brings the contact rings in connection successively with *R*3, *R*4, etc., each time cutting out some resistance, until the ring makes contact with *R*19, when the only resistance in the generator field is that between 50 and 49, and at that time, there is maximum voltage at the generator terminals and the motors are running at their maximum speed due to *constant excitation*. Up to this point, this constitutes the speed control as far as changes in the voltage of the generator, and the voltages impressed on the motor terminals, are concerned.

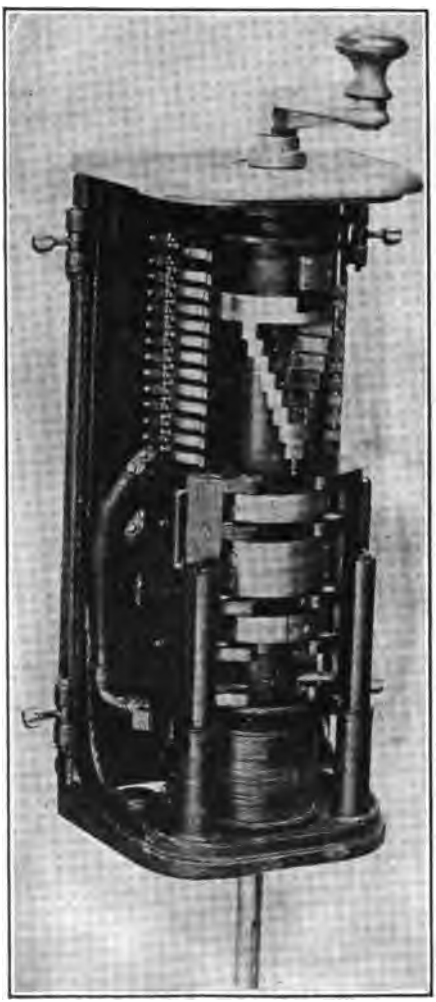


FIG. 162.—P-10 Controller for Combined Motor and Field Control.

Any further motion beyond that which connects *R*19 throws the lower finger of the two above *R*1 off its contact ring, when the generator field circuit is completed through finger *R*20 (the rheostat resistance for the generator being completely short-circuited), as the upper left-hand contact ring now connects with *R*20. This ring is connected with the one just below it, and the connection to the return field lead is made through the upper finger of the double fingers above *R*1.

Motor Field.—Current flows from the left-hand line lead, as for the generator field to the left-hand terminal of the three shown between the two motor fields, where it divides, going through and around the fields in parallel, to the right terminal of the three, and thence to finger *R*1. From here current flows to the contact ring above *R*1 and then back to the field line lead. This gives constant excitation to the motor fields and it remains constant during the movement of the controller up to the time that the generator field resistance is being cut out; that is, up to the point when the contact finger above *R*1 leaves its contact ring. At this point, the contact ring is just on *R*19, when the motor field current from *R*1 flows through all the contact rings to *R*19, then to block 49, through the resistance to 50, then to *R*20, and back to the field line as explained for the generator field.

Any further motion to the right throws *R*19 off its contact ring increasing the resistance in the motor field circuit to that between 50 and 47. Continued motion to the right, gradually adds resistance to the motor field circuits, weakening their fields and causing consequent increase of speed. This continues until all the resistance that was cut out of the generator field in the first half of the operation is thrown into the motor fields. Thus allows a double change of voltage; in the first operation the voltage of the generator increases due to cutting out of its field resistance while the motor fields are constant and in the second operation, the voltage at the terminals of the motors increases due to cutting in resistance in their fields, while the field of the generator remains constant.

The middle terminal of the three between the motor field switches connect to the return side of the field lead.

An inspection of the diagram will show that when the switches

are closed, this connection plays no part, as it is broken from the field leads by an insulated clip in the switches, but when either switch is open, the connection indicated by the arrows is made which has the effect of cutting out, or short-circuiting the controller rheostat, and the turret is then turned by one motor with a constant excitation.

Motor-Generator System.

The system of turret turning just described requires the sole use of one of the main generators, no matter what reserve power it may have. This is due of course to the varying voltage produced at its terminals by variations of the exciting current of its shunt field.

In the motor-generator system, a motor generator is interposed between the main generator and the turning motors, the voltage of the main generator remaining constant, and the remainder of its power may be used on other constant potential circuits.

A constant voltage is delivered by the main generator to the terminals of the motor of the motor generator, and the field of the motor is excited from constant potential mains. The generator armature of the motor generator has the same speed as the motor armature, and its field is varied by a suitable controller and rheostat.

The voltage developed by the generator will depend upon its speed and field excitation, so the voltage delivered to the terminals of the turning motors will be altered by any change in its speed or in its field. The speed will be practically constant and changes in the generator field are made by the controller and rheostat.

Specifications for Motor Generator Sets.

As a general guide to the requirements of motor generator sets the specifications prepared by the Navy Department for Turret-Turning Motor Generator Sets is given:

Specifications for Turret-Turning Motor Generator Sets Issued by the Navy Department.

(*To be Rated by the Kilowatt Capacity of the Generator.*)

1. To consist of a direct current 120-volt motor and a direct current 130-volt generator, with common frame having suitable supporting

feet. Both armatures to be mounted on a common shaft, with commutators toward the shaft ends, or between the armatures, as the contractor may desire. Unless otherwise specified, rotation to be right hand—*i. e.*, clockwise, facing motor end.

2. Sets to be of the semienclosed type with suitable openings in end shields only, for ventilation, inspection, and adjustment of brush riggings and for inspection of commutators. Openings other than in end shields are not permissible. All openings to be fitted with covers, which shall consist of rigid metal frames fitted with perforated sheet brass of at least No. 16 B. & S. gauge, or with the brass wire mesh; wires to be at least No. 16 B. & S. gauge. The sheet metal or wire mesh must be securely fastened to the frames and must be able to stand heavy shock without tearing away. They shall preferably be of slightly convex form to give additional strength. If sheet metal is used the perforations shall be circular, of not less than three-sixteenths inch nor more than one-fourth inch diameter. If wire mesh is used the wires shall be laid not less than three-sixteenths nor more than one-fourth inch center to center.

3. Covers to be capable of being readily opened and closed; this to be done without use of tools. To be readily fastened when closed in a positive and secure manner, such as will not permit their becoming loosened or displaced by continued vibration.

4. Drain cocks shall be fitted to the frame to permit drawing off water or oil which may collect on the interior, provided the construction is such as to form pockets in the frame.

5. Frame to enclose two separate magnetic circuits, each having four or more equally energized poles.

6. Shaft to be of steel, with accurately fitted journals. To run in two bronze self-oiling bearings, one at each end of the frame. To be provided with suitable means to prevent oil from bearings working along to armatures. Bearings to be provided with sight glasses on oil chambers and suitable drains for removal of oil at will.

7. Frame to be divided horizontally, the two parts to be bolted together, to permit ready removal of armatures and field coils.

8. Generator field to be compound wound in a manner which will adapt the machine for furnishing power for variable voltage control. The series winding is intended to compensate for the resistance drop in armature and leads to turret-turning motors due to sudden increase in load, and shall be such as to give not less than 30 volts with shunt field disconnected, 200 amperes flowing through generator armature, and set running at normal speed. A readily adjustable shunt of approved design shall be connected across the terminals of the series winding.

9. Sets to be designed for speed not exceeding 1500 revolutions per minute—the design to be with a view to minimizing weight and overall

dimensions; speed variation between no load and full load and from full load to no load not to exceed 6 per cent of normal.

10. Commutator bars or segments to be supported on a shell which must be directly attached to the spider or keyed to the shaft; bars to be of *hard drawn copper*, finished accurately to gauge; insulation between bars to be of carefully selected mica, gauged to uniform thickness and of such hardness as will wear evenly with the commutator bars.

11. Bars to line with the shaft and run true; to be securely clamped by means of bolts and clamping rings. There shall be no openings by which any foreign substance can get to the interior of the commutators. The commutators and brush rigging must be designed to permit handling heavy and fluctuating curents up to as high as 150 per cent in excess of normal full load current, both with full shunt field and very weak shunt field, all with brushes in fixed position.

12. Brushes to be of carbon; current density not to exceed 40 amperes per square inch; each brush on a stud to be capable of separate removal or adjustment, and means shall be provided for simultaneously shifting all brushes; brush holders to be of the sliding shunt-socket type; springs to be of material other than steel and must not be relied upon to carry the current.

13. Finished armatures to run true and be balanced both electrically and mechanically. The completed sets must run at all loads without noise or vibration.

14. A name plate to be fitted to each motor generator in a conspicuous place, containing the following data:

MADE FOR
BUREAU OF EQUIPMENT
BY
(*Name of maker here.*)
Req. No. —. Date —. Rating —.
Factory No. —. Volts —. Amp. —.
Field (Gen.) —. Amp. —. Ohms. —.

Factory number to be also stamped on the frame under the name plate.

15. Separate name plates shall be fitted to indicate which is the motor end and which the generator end.

16. The overall dimensions must not exceed the following: 15 kilowatts, 56 by 27 by 27 inches long; 25 kilowats, 68 by 28 by 28 inches long.

17. The design must be such that when installed in confined spaces, with but 4 inches clearance at each end, the upper parts of the field frames can be lifted and the armatures removed or replaced.

18. There shall be no wires carried to the exterior of the frames, but the internal arrangement shall be such that the connecting wires

can be suitably carried to their proper contacts with the machine assembled. These wires will be carried in conduit pipes which will tap directly into the lower part of the frames; conduit bosses shall be fitted on each side of each end, but the frames need not be tapped by the builder unless specifically required. Two armature leads and one field lead will pass to the motor end; two armature leads and two field leads will be taken from the generator end. On each side of motor end and of generator end there shall be two bosses for 1¼-inch iron pipe size and one for ¾-inch iron pipe size.

Connections of Panel and Rheostat for Starting Motor-Generator Sets for Turret-Turning Equipments.

These are shown in Fig. 163.

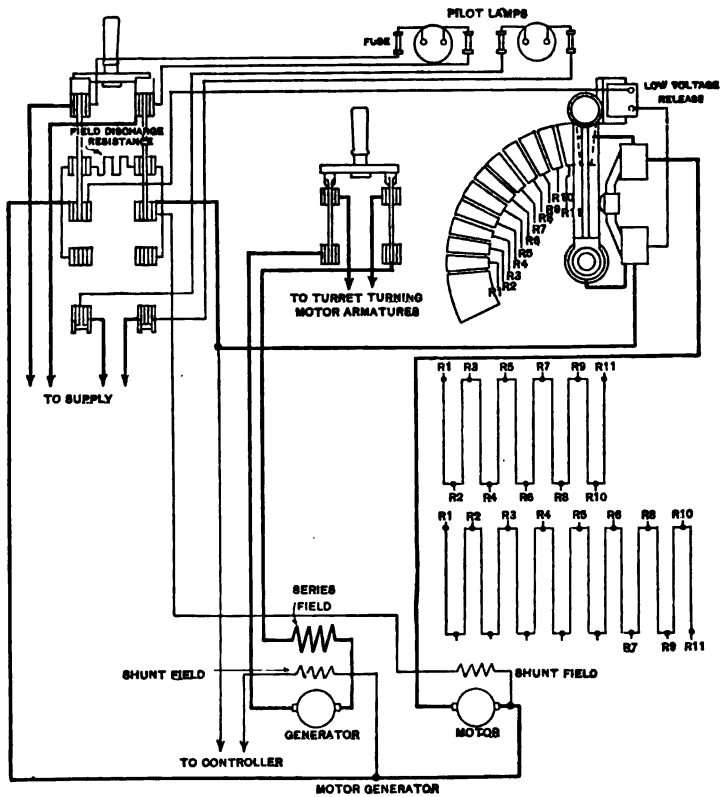


FIG. 163.—Connections for Starting Motor-Generator Sets for Turret Turning. Gen. Elec. Co.

The two supply mains on the left run, one to each of two distribution boards, and the motor line is connected to the hinge end of a two-pole, double-throw switch, so current from either board may be used.

The field of the generator is controlled by a controller and rheostat similar to that shown in Fig. 160.

The starting resistance for the motor is of slightly different design from any of those previously designed, but presents no new principle, and the connections are easily traced.

In another system of installation of the motor generator, speed control is effected by changes in the fields of the generator of the motor generator and the turning motor, similar to that shown in Fig. 161, in which the generator shown may be considered as the generator of the motor generator.

Rotary Compensator System.

This system is designed and supplied by the General Electric Company. It consists of a small motor driving the turret through a high gear reduction by means of an electric clutch, and a large motor directly connected to the turret through a lower gear reduction, the gear reduction being so designed that the turret will be turned at about the same speed by the small motor when operating at maximum as by the large motor when operating at minimum speed.

The electric clutch will disconnect the small motor mechanically at the time the armature of the large motor is electrically connected to the source of power, the large motor being continuously turned when the turret is in motion, while the small motor will be turning at variable speed without load when the large motor is turning the turret.

The connections of this system are shown on Fig. 164. The variation in speed of the large and small motors together with the change in gear reduction above mentioned, will give delicate speed control of turret between approximately $\frac{1}{4}°$ per minute and 100° per minute.

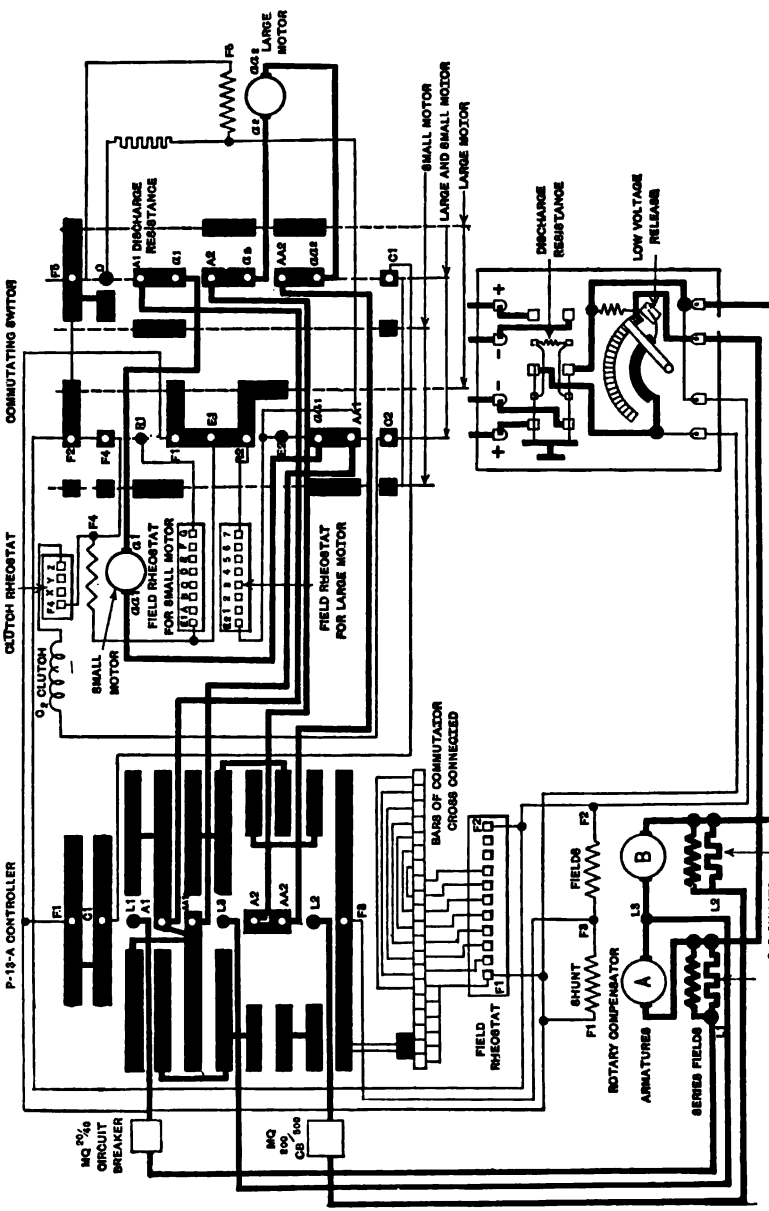


FIG. 164.—Connections of Rotary Compensator System for Turret Turning. Gen. Elec. Co.

There will be seventy-five speed positions of the controller, the approximate speed of the turret at various positions being shown on curve sheet (Fig. 165).

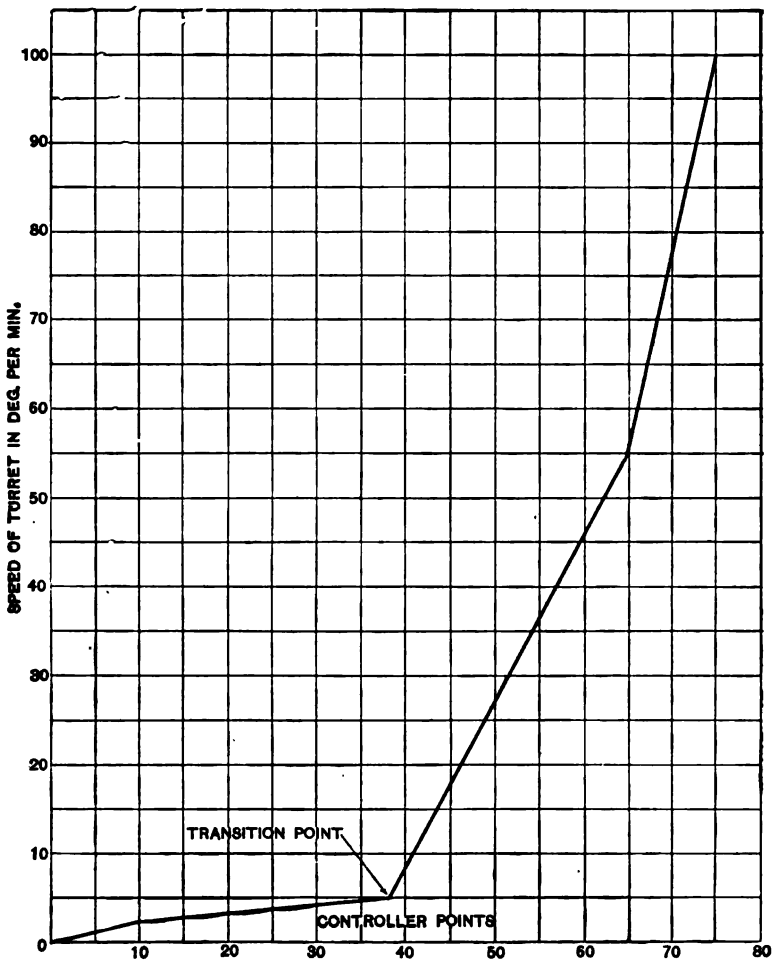


FIG. 165.—Speed Curve.

The variation in speed of the machines will be upon the variable voltage system obtained from a rotary compensator. This compensator consits of two armatures mounted upon the same shaft, revolving in two separate magnetic fields, each supplied with series and shunt windings, the connections of the separately excited shunt fields being so made that the strength of the fields are varied by means of a shunt resistance operated by the controller, the voltage of one armature being raised when the voltage of the other armature is reduced. The small motor armature is placed in multiple with one armature winding of the compensator and is increased in speed from a minimum to maximum, at which position of the controller the voltage of the second armature is at a minimum, allowing the large motor to be started under these conditions, and thereby increasing the speed of the turret to the above-mentioned maximum, while the second armature is cut out mechanically from operating the turret.

The two motors are connected to the system through a commutating switch (Fig. 166) designed for three positions to meet the following conditions:

1. Both motors operating the turret.
2. Small motor only operating turret (large motor cut out).
3. Large motor only operating turret (small motor cut out).

In order to give a little greater speed variation when the small motor or the large motor is operating independently, than is obtained from either motor when they are operating together, field resistance is inserted so that under normal conditions the small motor will run at full field, and the large motor at slightly weakened field, but when running separately the small motor will run at weakened field to give approximately 6½° per minute of turret maximum, with a corresponding increase in the minimum speed, and the large motor will run at a speed to give approximately 4½° per minute of the turret with a corresponding reduction in the maximum speed, the speed of the turret at transition from small to large motor under normal conditions being approximately 5½° per minute.

These field rheostats are inserted in the motor fields by suitable connections at the commutating switch.

The controller (Fig. 167) is designed to give the above maximum speed in each direction by a movement of the cylinder of 170°

FIG. 166.—52-A Commutating Switch. Gen. Elec. Co.

either side of the "off" position, the motion of the cylinder in either direction from the "off" position to the starting position for the small motor being 18°.

The clutch is designed to drive the turret from the small motor

and will operate promptly and effectively. It will be provided with a resistance to be placed in series with the coil in order to give

FIG. 167.—P-13 A Controller. Gen. Elec. Co.

more prompt action, and allow adjustments to meet the conditions of installation.

The construction of the rotary compensator is considered in Chapter XX, Dynamo Electric Machines. The motors present no

unusual features and are similar in construction to those described in the chapter on Service Motors.

Rotary Compensator Starting Panel.—The starting panel for the rotary compensator will be of the flame-proof type.

It will consist of an insulating panel carrying at the top a double-pole, single-throw **line switch**, below which will be located a **starting rheostat switch** with no-voltage release.

The starting resistance will be mounted behind this panel, and terminals for leads will be suitably located on the panel. The entire panel and resistance will be mounted in a water-tight, cast-iron box with the cover held in position by screws and wing nuts, and provision will be made so that the main line and starting switches can be operated from the outside of the box without removing the cover.

Magnetic Clutch.—This consists of two steel discs, upon one of which the worm gear will be mounted by the purchaser, and the other carrying the energizing coil and collector rings. Both discs are mounted upon a sleeve, which is rough finished inside to be bored and splined by the purchaser to fit the shaft, upon which it will be keyed.

The first disc rotates freely upon this sleeve, being held by collars from longitudinal motion, while the second disc is keyed to the sleeve and arranged so that it can move longitudinally and thus release the clutch when the energizing circuit is open.

The collector rings are mounted upon a hub projecting from this first disc, upon each of which two carbon brushes bear, these being provided with the brush holders which are fastened to the turret at the time of installation.

At 10 R. P. M. this clutch will transmit 150 per cent of full-load torque of the small motor, and will stand full current, which can pass through it in series, with its resistance at 120 volts, without temperature rise exceeding 50° C. at the end of this time, measured by resistance. Or, in other words, it will deliver 2¼ H. P. at 10 R. P. M.

A rheostat in series with the coil is furnished in order to obtain more prompt action, and reduce the voltage at the terminals to approximately 60 volts.

Controller.—The P-13-A controller is designed to control two turret motors operating through different gear reductions so that the motion of the turret shall be absolutely positive in its action and in complete control of the operator.

It will allow the turret to move by small increments and be turned at seventy-five definite speeds in either direction, there being a large number of intermediate speeds available between each pair of above-mentioned speeds.

Each speed will be continuous and uniform for the complete distance through which the turret can be turned.

Classification.—This controller is classified as P-13-A and it consists of the following parts:

Frame.—The frame is of cast iron with feet at the bottom. The cap-plate is detachable and fastened to the frame by flat-headed screws. This cap-plate will be marked to indicate "off" position of the controller and the full "on" position of the controller, with two marks showing the high-speed running position of the small motor and the low-speed position of the large motor, the space between these marks being the movement of the controller cylinder necessary to ensure transition between the two motors.

The front cover will be of sheet iron held in position by hinge bolts, two on each side, so that it can be swung to either side or removed entirely if desired.

A back cover of sheet iron will be provided for protection of the terminals, the studs of which project through the top of the controller frame.

Cylinder.—The cylinder carrying the contact segments will be supported upon a steel shaft insulated from it by a special compound.

Shaft.—The shaft will be of steel, extended at the top for the attachment of a hand wheel or operating shaft and provided with a water cap.

The bottom of the shaft extends beyond the controller for the attachment of the automatic stop. This shaft carries at the top and just below the cap-plate a star-wheel with one notch at the "off" position into which a pawl operated by a spiral spring will fall.

Contact Fingers and Segments.—The upper half of the cylinder will consist of contact segments for controlling the armature circuits of the two motors, the clutch circuit, and one lead from the compensator field circuit, these being mounted upon special insulated supports.

One row of easily renewable and adjustable fingers will make connections.

Field Connections.—Connections to the field rheostat of the compensator are made through a carbon brush, connected to the finger on the lower segment of the upper part of the cylinder above described, and bearing upon the ends of a commutator mounted concentric with the shaft and supported from the back of the controller frame.

Leads attached to the lower ends of these commutator segments pass to a connection board at the bottom of the controller, to which the taps to the field rheostat are made.

The above-mentioned carbon brush being attached at the junction of the two compensator shunt fields, controls the voltage at the two ends of the compensator by its position and consequent division of resistance of the two parts of the rheostat, which are in multiple with the two shunt fields.

Since the resistance of this carbon brush forms a part of the shunt circuits to the two fields, its exact position relative to the two segments upon which it bears affects the field currents of the compensator, and as this brush can take an indefinite number of positions in passing from one segment to the next a corresponding indefinite number of speeds of both motors can be obtained.

The commutator is cross-connected, allowing the brush during the first half of its travel to pass over the rheostat taps in one direction and during the second half of its travel to pass across them in the opposite direction, this being necessary in order to give the proper speed control of the two motors.

The carbon brush is driven through the train of gears making it turn at approximately double the angular speed of the cylinder, so that when the main shaft has turned approximately one-half a revolution in order to give full speed of turret in one direction, the brush travels nearly 360°, the difference being due to the dead spaces in the commutator.

Terminals.—The terminals for the main contacts at the top of the cylinder consist of studs to which the leads can be attached, and which pass through the back of the controller into the finger bases where they are held by set-screws. This will allow the large wires to be brought up behind the controller and covered after installation by the sheet-iron case previously described.

The leads from the commutator will pass through an annular opening in the bottom of the controller frame, and be attached to studs mounted upon an insulated connection board, to which the leads from the rheostat can be attached, thus allowing the commutator board to be readily disconnected from the resistance leads. The connection board will be provided with a sheet-metal covering to protect the terminals from external injury.

Electric Brake.—The main cylinder is connected so that when it is in the "off" position, the armatures of the large motor and small motor will both be short-circuited, thus producing an electric brake.

Commutating Switch.—The commutating switch (Fig. 166) is similar, in general construction, to the turret-turning controller, but as it is only designed to make desired connections for various conditions of operation and not to open circuits carrying current, it varies in some details from controller construction.

Classification.—The commutating switch consists of the following parts:

Frame.—The frame is of cast iron, furnished with four feet at the back for attaching to the support. The cap-plate is of brass, detachable, and fastened to the frame by flat-headed screws. It will be marked "small motor," "small motor and large motor," "large motor," and will be provided with a brass handle for turning the cylinder to the desired position.

The cover is of sheet iron, held in position by hinge bolts, two at each side, so that it can be swung to either side or removed entirely if desired.

Cylinder.—The cylinder carrying the segments will be of wood impregnated by paraffin supported upon a steel shaft.

Shaft.—The shaft will be of steel provided with a star-wheel at the top with a pawl for holding the cylinder in the desired position.

Contact Fingers and Segments.—The contact fingers and segments will be similar to those furnished with standard controllers.

Terminals.—The leads to the above fingers will pass through an opening in the bottom of the frame behind the cylinder, provision being made for convenient attachment to the fingers, which are located in two rows, one at each side of the frame, it being necessary to remove the cylinder from the frame in order to attach the leads to the finger bases.

Rheostats.—There will be four rheostats in the field clutch circuits of this equipment.

Each rheostat consists of a cast-iron frame supporting a fiber panel on which are mounted the terminals of the resistance, these terminals being marked as shown on Fig. 164.

Several terminals to allow adjustment of resistance after installation are provided. The rheostat for use with the compensator and controller is provided with a considerable number of extra terminals, the resistance being so graduated as to give a speed curve to the turret approximately as shown on curve sheet.

The resistance will be of the "EC" or Enclosed Card type.

Circuit Breakers.—There will be supplied two automatic magnetic blower circuit breakers, one for the large motor and one for the small motor.

Each of these circuit breakers will be enclosed in a water-tight cast-iron box which will be furnished with bosses on the sides to be drilled out for conduit, and will have projecting handles, so that the breakers can be set or tripped from the outside, without opening the box.

Elementary Principle of the Rotary Compensator.

The foregoing description of the actual apparatus will make clear the connections in the elementary diagram of connections in Fig. 168.

A and B are the armatures of the rotary compensator, and it must be remembered that they are mounted on the same shaft, so turn at the same speed, and each has its own separate field S and S'. L_1 and L_2 are the armature leads from the starting panel and l_1 and l_2 are the field leads from constant potential source.

Motor armature D is in parallel with machine B and C in parallel with A. D corresponds to the small motor in the previous de-

scription and C to the large motor. R is a resistance between the shunt leads and connected by an arm H to the junction of the two fields of A and B.

If the starting switch is closed and the fields of both A and B energized with arm H in mid-position, both armatures of A and B will run as motors, their armatures being in series. During this stage of operations, neither C nor D is connected to their armatures.

The fall of potential through armatures A and B will be equal and the sum of their brush differences of potential will be equal to the difference of potential in the leads L_1 and L_2. This will be the case because the fields of each are equally excited.

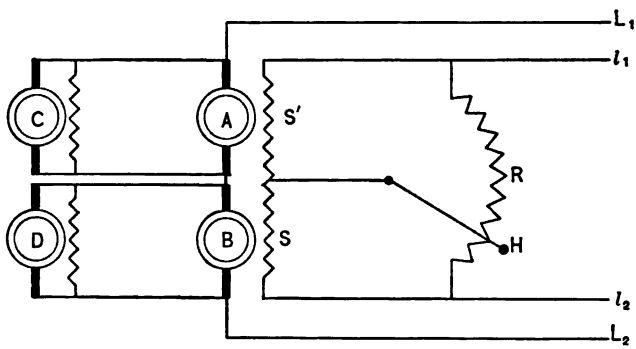


FIG. 168.—Elementary Connections of Rotary Compensator.

If $\mathfrak{E}_1$ = difference of potential across brushes of A,
$\mathfrak{E}_2$ = " " " " " " B,
$\mathfrak{E}$ = " " " " line,
E_1 = Counter E. M. F. due to A,
E_2 = " " " B,
C_a = armature current,
r_{1a} = " resistance of A,
r_{2a} = " " " B.

Then at any time

$$\mathfrak{E}_1 - C_a r_{1a} = E_1$$
$$\mathfrak{E}_2 - C_a r_{2a} = E_2,$$

adding

$$\mathfrak{E} - C_a(r_{1a} + r_{2a}) = E_1 + E_2.$$

Suppose the field of S is short-circuited by moving the arm H so as to cut out all resistance, then the excitation of S will fall to practically zero, in which case

$$E_2 = 0,$$

or

$$\mathfrak{E}_2 = C_a r_{2a}$$
$$\mathfrak{E}_1 - E_1 = C_a r_{1a}.$$

As the field of S' is fully excited, E_1 is very nearly to $\mathfrak{E}_1$, and their difference is small, therefore C_a is small, and $C_a r_{2a}$, the difference of potential across B is very small. The operation of decreasing the resistance in parallel with S has been to lower the voltage of B and raise that of A.

As the resistance of R is gradually cut in by moving the arm H up, as shown, the fall of potential across B gradually increases, because the field S increases and consequently E_2 increases. E_1 must therefore decrease and the fall of potential across A decreases in such a ratio as to keep the sum of $\mathfrak{E}_1$ and $\mathfrak{E}_2$ equal to $\mathfrak{E}$.

When the arm H is in its mid-position the fields are equally excited and the fall of potential across A and B is each equal. Further movement of H will more or less short circuit S', when by similar reasoning it is seen that the fall of potential across A decreases while that of B increases.

D is the small motor connected in parallel with B and at any time it has impressed on its brushes the voltage across the brushes of B. Consequently, if connected at the low voltage, as the voltage of B increases D will gradually speed up. At a certain point when the voltage of B has increased to near its maximum value and A decreases to its minimum value, the armature of C is connected to A. Its gearing is such that it takes up the speed of the turret just where B was disconnected, and the resistance is now varied in the reverse sense so that the voltage of A increases while that of B decreases, thus causing the motor C to speed up.

When D is running with a low voltage impressed on its brushes, it may be that the current is not sufficient to drive the three armatures, in which case more current will flow from the line and B may act as a generator supplying the extra needed current. When

D has a high voltage, E_2 is high and probably all the current comes from the line through A.

Variable Speed Gear.

The mechanical device known as variable speed gear has been installed for turret training and will be used for gun elevating, and from its description it will be seen that it may be applied to any apparatus in which a large variation of speed is required.

The variable speed gear as furnished by The Waterbury Tool Company, is a machine for transmitting rotary torque at variable speeds and in either direction without steps or abrupt gradation, while the source of power rotates continuously in one direction without any necessary change of speed. This source may be an engine of any kind, an electric motor or any revolving shaft or mechanism from which it is desired to transmit power. There are no gears within the transmitter itself, and, as the medium of transmission is oil, which is practically incompressible, the driving is very positive.

Functionally the machine consists of two mechanisms, called respectively the A end and the B end (Fig. 169). The function of the A end is to receive the power by being coupled, geared and belted to the source of power and to transmit it to the B end by transferring oil from a low-pressure chamber to a high-pressure chamber. In other words, the A end is an oil pump:

It is the function of the B end to act as an oil engine operated by the pressure of the oil pumped to it by the A end, and exhausting the oil back into the low-pressure side of the A end.

The two ends A and B are made up of exactly similar parts, although these parts are not necessarily of the same dimensions. Moreover, as the controlling is usually done entirely on the A end, the B end is not equipped with the controlling parts unless for some special purpose.

The two ends A and B may be built as separate mechanisms connected by conducting pipes, or they may be combined into one machine, the two parts being separated by a mid-plate. A mid-plate becomes two end-plates when the machine is constructed as two separate mechanisms.

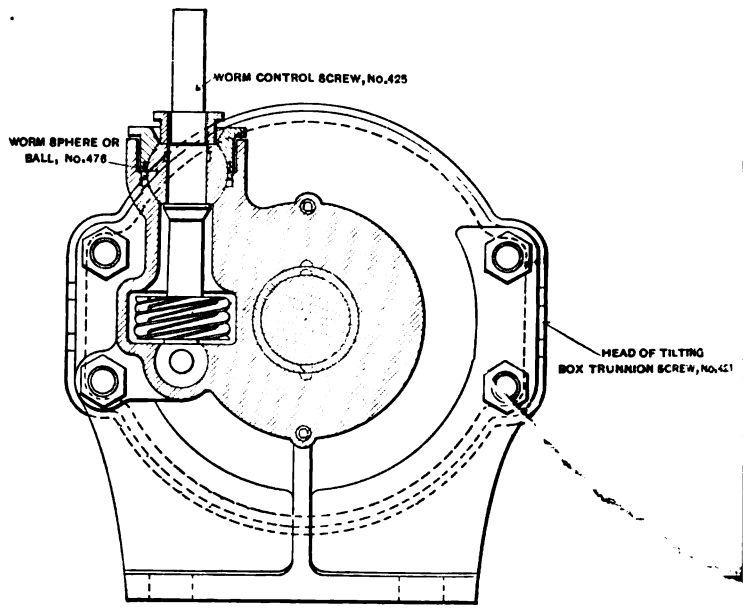
Important Parts and Their Functions.

Case.—An outer case, usually a steel or bronze casting, encloses the working parts and forms a reservoir, which should be kept entirely full of oil at all times. The case also supports the tilting-box trunnions which bear the whole thrust and torque of the driving power. In some types of construction the shaft passes through the end of the case where it has one of its bearings, while the other bearing is in the mid-plate. In other types, where the *A* ends and *B* ends are separated into different mechanisms, the shaft may pass through and have its bearing in the end-plate only.

Shaft.—The shaft in the *A* end receives the power and the shaft in the *B* end gives up this power. On the shaft and rotating with it are the cylinder barrel and the socket ring.

Cylinder Barrel (Figs. 169 and 170).—The cylinder barrel is keyed to the shaft by two swiveled keys, allowing the barrel a very slight movement like that of a universal joint and also allowing it to move freely a short distance along the shaft under the pressure of two springs, which are only strong enough to slide the barrel along the shaft and keep it pressed lightly against the face of the end-plate, or mid-plate, as the case may be. When the machine is transmitting power, the pressure of the oil itself, by a peculiar construction of the cylinder ports, keeps the faces of the barrel and plate in contact with just force enough to prevent excessive leakage. In the barrel are the cylinders arranged parallel with the shaft, and in the cylinders, piston operate. Each piston is connected with the socket ring by a connecting rod. Each connecting rod consists of a shaft with a ball on each end, one ball being held in a socket in a piston, the other in a socket in the socket ring. The sockets are lubricated through a hole extending lengthwise through the connecting rod, the balls and the end of the piston, which is in communication with the oil under pressure.

Socket Ring.—The socket ring is connected rotatively with the shaft by an intermediate ring and trunnions forming a universal joint. The universal joint must be so constructed as to permit the socket ring to rotate with the shaft, but at any angle to the shaft up to the maximum provided for in the designs, say 20 degrees. The connection between the socket ring and the shaft



SECTION THROUGH C-D

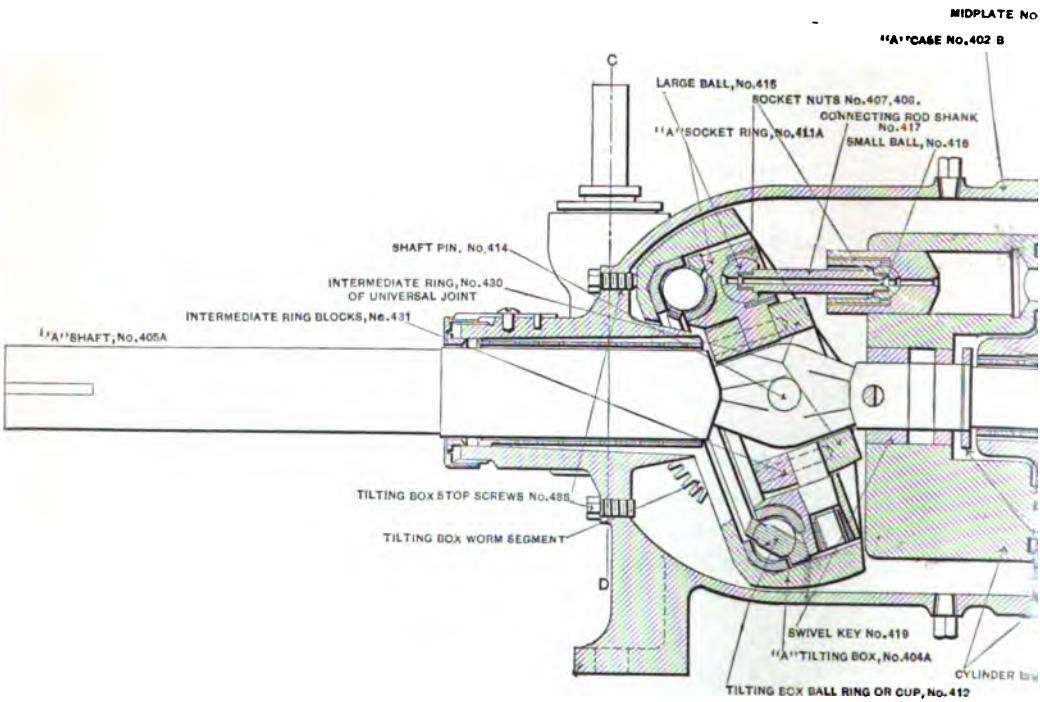
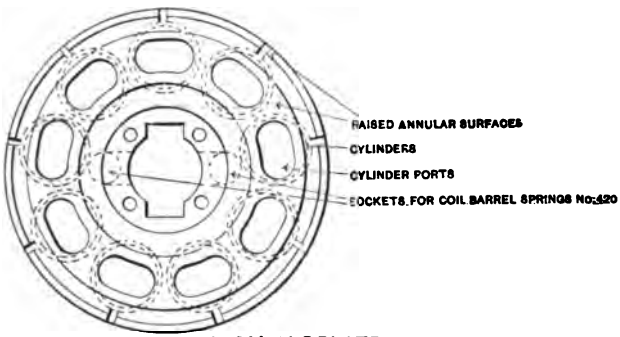
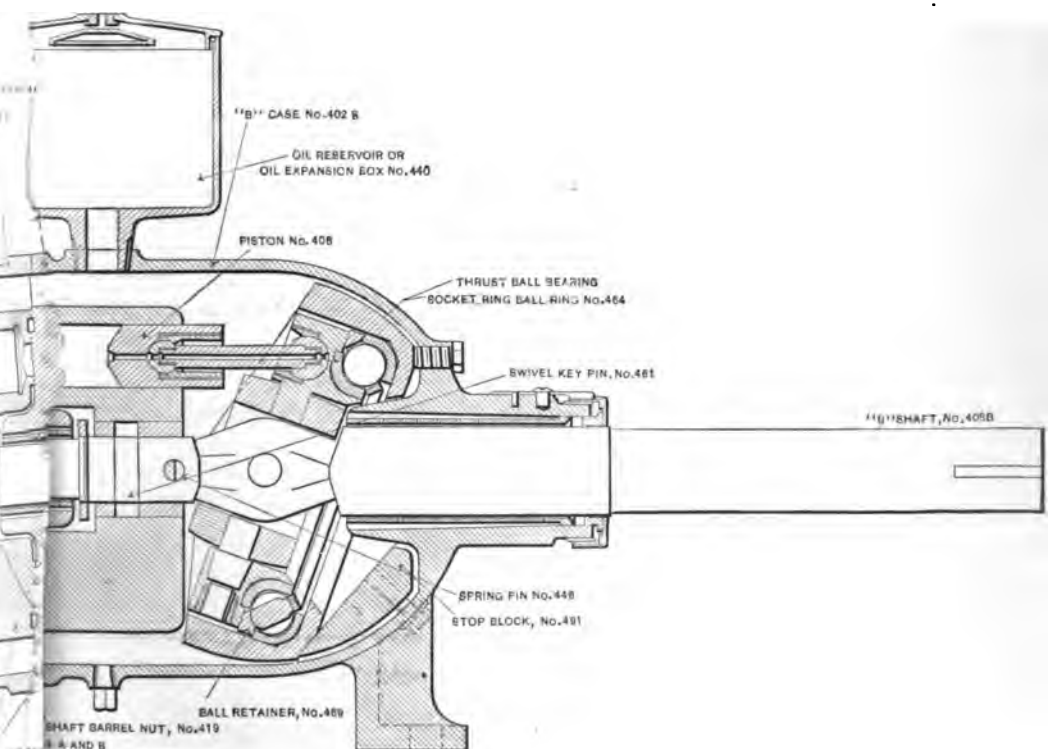


FIG. 169



CYLINDER BARREL SEEN FROM MIDPLATE

FIG. 170.



169 ble Speed Gear.

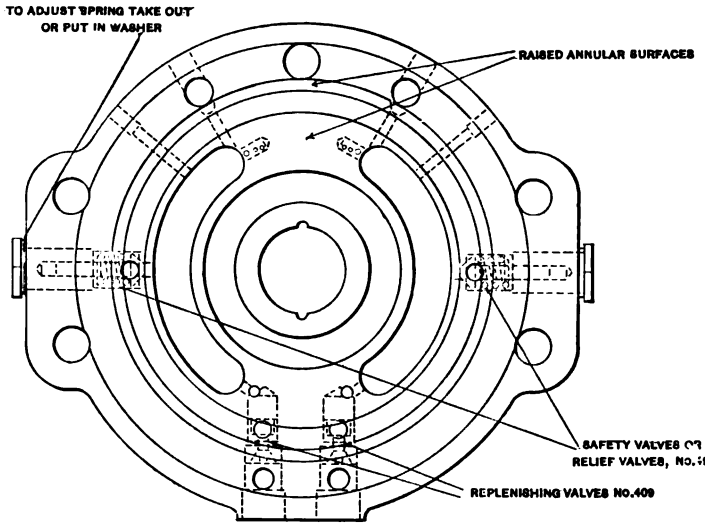
does not receive the end thrust of the oil pressure on the pistons, but it does transmit the whole torque, in the *A* end from the shaft to the ring, in the *B* end from the ring to the shaft. The *end thrust* is against a large ball-bearing between the socket ring and the tilting box.

Tilting Box.—The tilting box is a very important part of the mechanism inasmuch as the speed and direction of rotation depend upon the tilting of the box at different angles to the shaft. It swings on two trunnions which pass through each side of the case and so may be considered as a fixed part of the case itself, capable of being tilted on its trunnions at the will of the operator but independently of the shaft rotation. A worm wheel segment forms a part of the box of the *A* end, and engages with a control worm screw by which the box is tilted on its trunnions. The box of the *B* end may be equipped exactly like that of the *A* end, but generally the box of the *B* end is set at a fixed angle when the machine is assembled and no provision is made for a change of angle. In designs having the shaft extend through the case, there is a hole through the bottom of the box through which the shaft passes and large enough to allow of tilting the box to its extreme angle without coming in contact with the shaft. Where the shaft passes through the end plate only, the box may have an entire bottom.

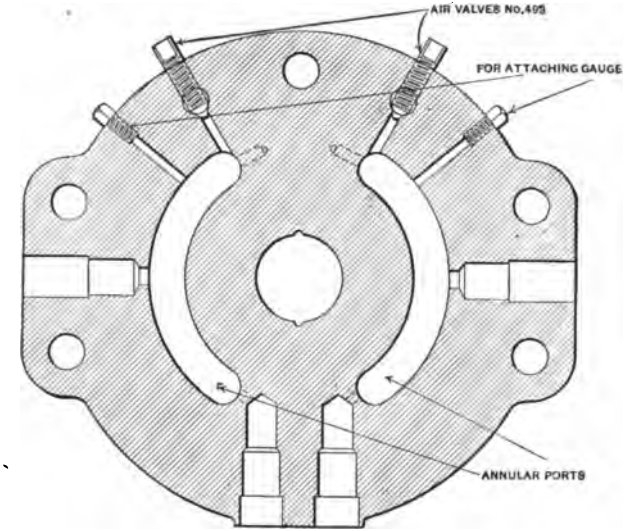
The most important functions of the tilting box are two: first, to furnish a support for the ball thrust bearing against which the socket ring rotates; and, second, to vary the lengths and direction of the piston strokes by varying the angle of the tilting box with the shaft.

Control Screw.—The control screw is a worm screw engaging the worm segment of the tilting box and having its shaft extend through the case. The turning of the control screw controls the speed and direction of the *B* end by determining the direction of flow and the quantity of oil supplied to the *B* end. The shaft of the screw passes through a ball in the wall of the case, allowing the screw to be adjusted into close mesh with the segment by an adjusting screw which extends through the end of the case and presses against the bearing block of the inner end of the screw shaft.

Mid-Plate or End-Plate.—The mid-plate or end-plate (Fig. 171),



MIDPLATE, No.401 "B" FACE



MIDPLATE SECTION THROUGH XY

FIG. 171.

as the case may be, receives the cylinder barrel or barrels against one or each of its faces. The contact is a raised annular surface. In the barrel contact surface ports open from each cylinder. In the plate contact surface there are two long ports forming annular arcs diametrically opposite each other and opening into oil chambers or passages leading to corresponding ports in the other face of the plate or in the other end of the machine. When the machine is transmitting power, the pistons of the *A* end, moving by virtue of the angle of the tilting box, draw in oil from one of the chambers. and carrying it across the land which separates the two annular ports, force it into the other oil chamber; the oil thus transferred by the *A* cylinders is carried back by the *B* cylinders. Each of the oil chambers of the plate is provided with check valves, called replenishing valves, admitting oil from the case reservoir to replenish leakage. In one of the chambers the oil is under pressure and holds the valve closed; in the other chamber the oil is not under pressure and oil from the case is free to pass up through the valves. If it were not for the replenishing valves, the leakage of oil past the pistons and between the surface of the barrel and plate would tend to create a vacuum in the low-pressure chamber. Which of the chambers is high pressure and which low is determined by the direction of rotation together with the direction of the angle of the tilting box.

Applicability.—The machine is applicable as a transmission device wherever there is an irreversible and constant source of rotatory power which it is desired to transmit at variable speeds and in either direction at will. As the changes of speed are perfectly smooth along a perfect curve in either direction from zero to the maximum without step or jump, it will be seen that its applicability covers a very wide range. Moreover, the speed of the *B* end is limited or restricted by the angle of the tilting box of the *A* end. The machine thus acts as a positive brake holding the speed of the *B* end under the absolute control of the operator.

Efficiency.—The efficiency of the machine has been found by numerous tests to be more than 80 per cent when running under normal conditions. When the *B* end is running at very slow speeds, the efficiency is considerably less, but no matter at what

speed the *B* end runs, the full torque due to the oil pressure is maintained, and the only limit to this torque is the strength of the machine to withstand the pressure, and the small leakage, which, although it becomes less, as the speed is reduced, yet at extremely slow speeds approaching zero and under heavy pressure, is large in proportion to the oil actually pumped, or in active circulation. Measurements made at half load and at full speed have shown a leakage of 2½ cubic inches in an active circulation of 4800 cubic inches per minute. Very great smoothness and regularity of rotation are easily attained at speeds as low as *one rotation of the B end in one minute.*

It should be understood that this leakage does not escape from the machine, but only passes from the high pressure side into the case reservoir, thence through the replenishing valves to the low-pressure chamber.

Gun-Elevating Equipment.

The two general systems used in this equipment are the **direct system** and the **motor-generator system.**

In the *direct* system, the elevating motor armature is connected directly to the constant potential mains of the ship and the variation in speed is obtained by varying the resistance in series with the armature. This does not allow of very fine control, and the present practice to obtain very small changes of speed is to use the motor generator between the power mains and the elevating motor, the field of the generator being varied to change the voltage impressed on the motor terminals.

Direct System.—The first system is illustrated in Fig. 172 and the elementary diagram in Fig. 173.

The equipment consists of the **shunt motor, controller, rheostat** and **switch panel.** The controller is of the *R* type (rheostatic control) and arranged to give five speeds in either direction. It has a short-circuiting contact in the *off* position, closing the armature circuit and causing it to act as a powerful brake.

The **switch panel** is provided with a double-pole, single-throw switch, a single-pole magnetic circuit breaker, and a discharge

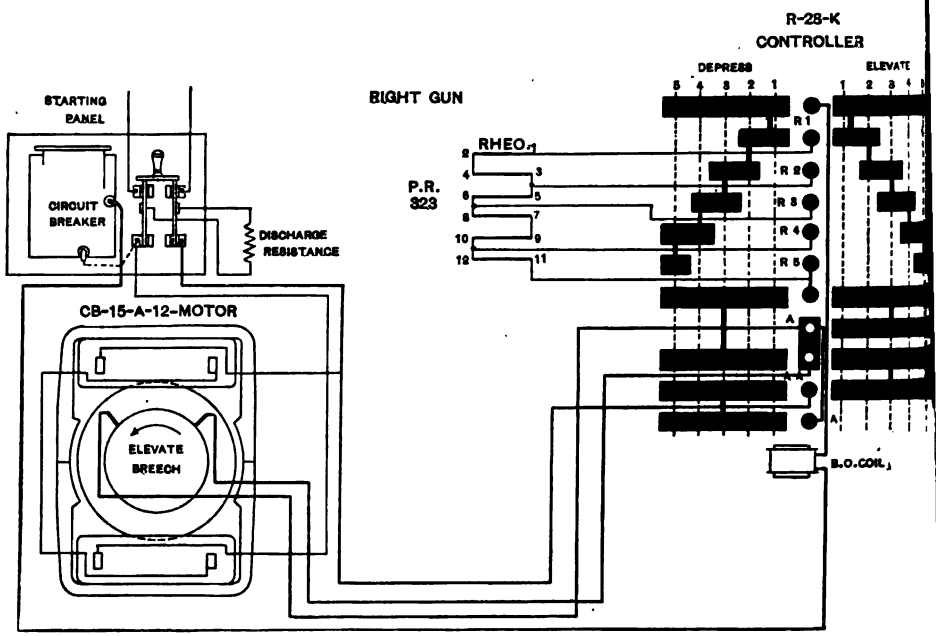


FIG. 172.—Connections for Elevating Equipment of Turret Guns.
Gen. Elec. Co.

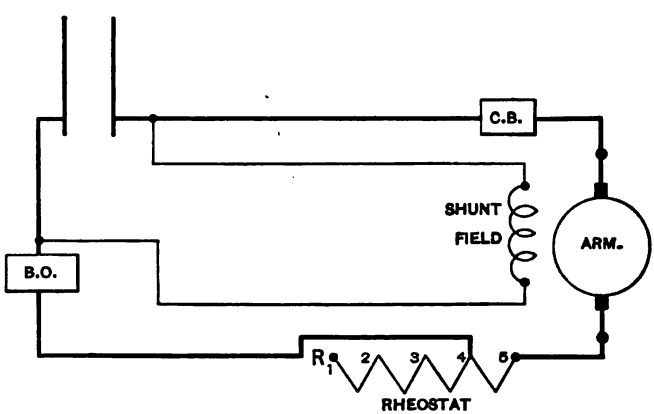


FIG. 173.—Elementary Diagram of Electrical Connections.

resistance arranged to be cut into the field circuit when the field switch is opened.

The rheostat is of the pressed-ribbon type previously described.

Motor Gearing.—The mechanical connection between the elevating motor and the gun is effected by a series of bevel gears and shafting; one inclined shaft is threaded and on this shaft travels the block to which the gun-elevating rods are attached.

An athwartship shaft is carried to the outboard side of the turret, and on its end is fitted a small sprocket wheel which can be driven by a sprocket chain from a second wheel, operated from a crank on the turret floor. This is worked by hand in case of electrical failure of the elevating equipment.

Motor-Generator System for Gun Elevating.—Motor generators are used for turret turning and gun elevating, the principles in each case being identical and for purposes of illustrating the general system connections are given in Fig. 174 for 8-inch elevating equipment.

The elevating equipment consists of the **motor generator, elevating motor, motor starting panel** and **speed-control rheostat.**

The starting panel contains a double-pole, single-throw switch, fuses, starting resistance and no-voltage release. The fields of the motor of the motor generator and of the elevating motor are excited by constant potential, while the field current of the generator is varied by the speed-controlling rheostat, thus changing the voltage at its terminals and at the motor terminals, consequently producing variable speed.

The speed-controlling rheostat has been described in the chapter on Controlling Devices. It serves the double purpose of varying the speed and of changing the direction of rotation of the armature.

While the direct method of gun elevating only permits of four or five different speeds, this method allows of any speed between the minimum and maximum.

Gun-Loading Equipment.

The electrical equipment for rammers of turret guns consisting of a **motor, series wound, controller, rheostat** and either a **main line switch** or **circuit breakers.**

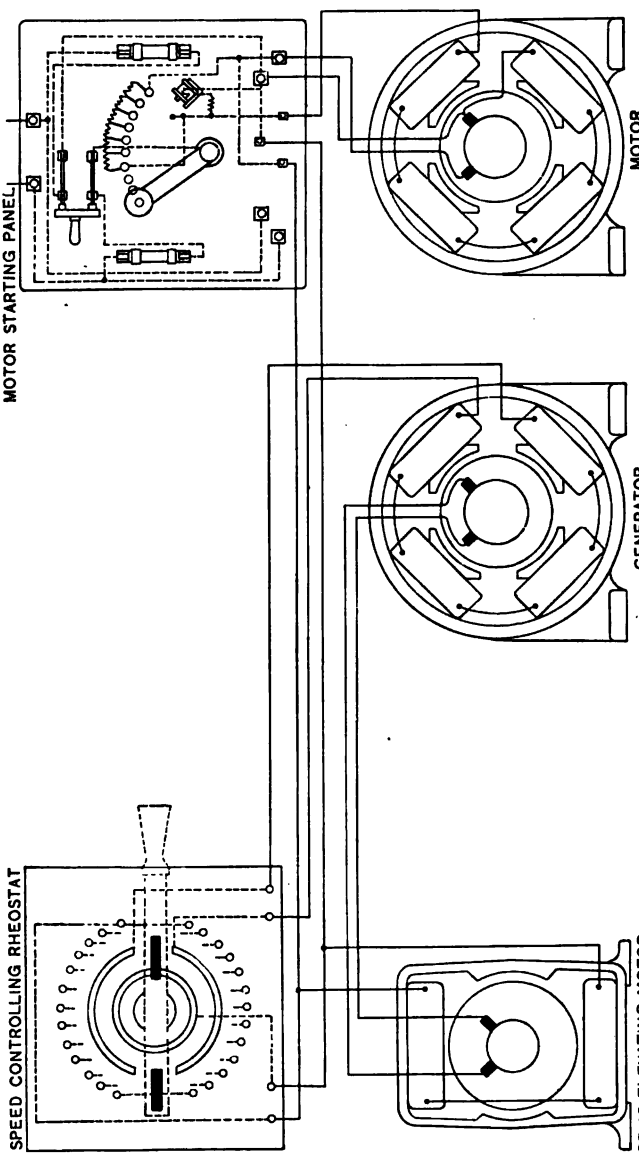


FIG. 174.—Eight-inch Elevating Equipment. Gen. Elec. Co.

The ordinary *R* form of controller (rheostatic) is used and **pressed-ribbon** rheostat. Fig. 175 shows the connections of the equipment, showing five speeds each way for the rammer. Fig. 178 is of later design, the principal differences being that it has two single-pole circuit breakers mounted in a cabinet and the backward motion of the rammer only has two speeds while forward motion has five.

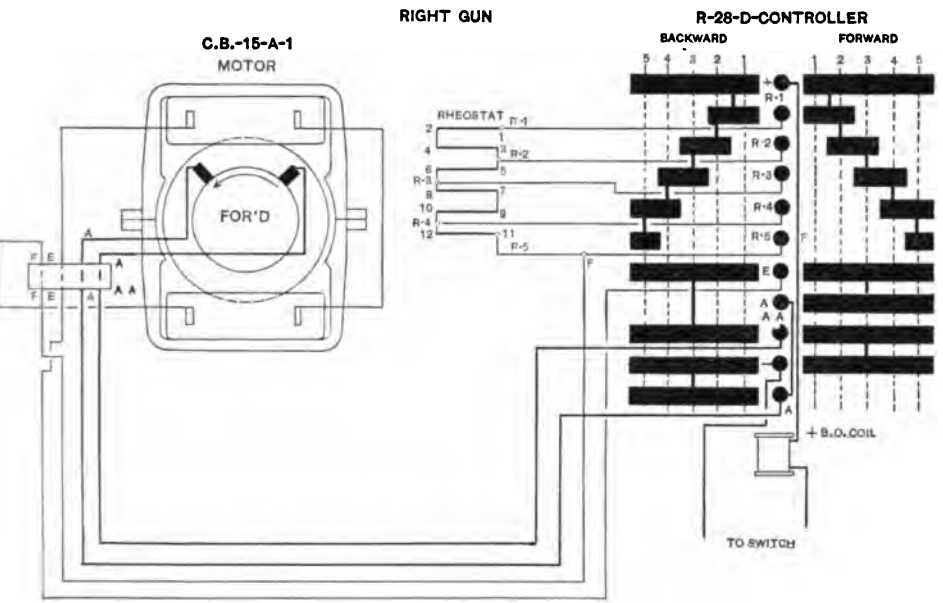


FIG. 175.—Electrical Connections of Gun Rammers. Gen. Elec. Co.

The elementary diagram of connections is shown in Fig. 177.

A view of the controller showing the method of mounting the resistances for the later type is shown in Fig. 176.

The armature shaft carries a pinion which is loose upon it and which is driven by a friction clutch keyed to the armature shaft set up by means of a spiral spring so that any unusual torque on the pinion will cause the latter to slip freely on the shaft. This pinion engages direct on the gear on the rammer case.

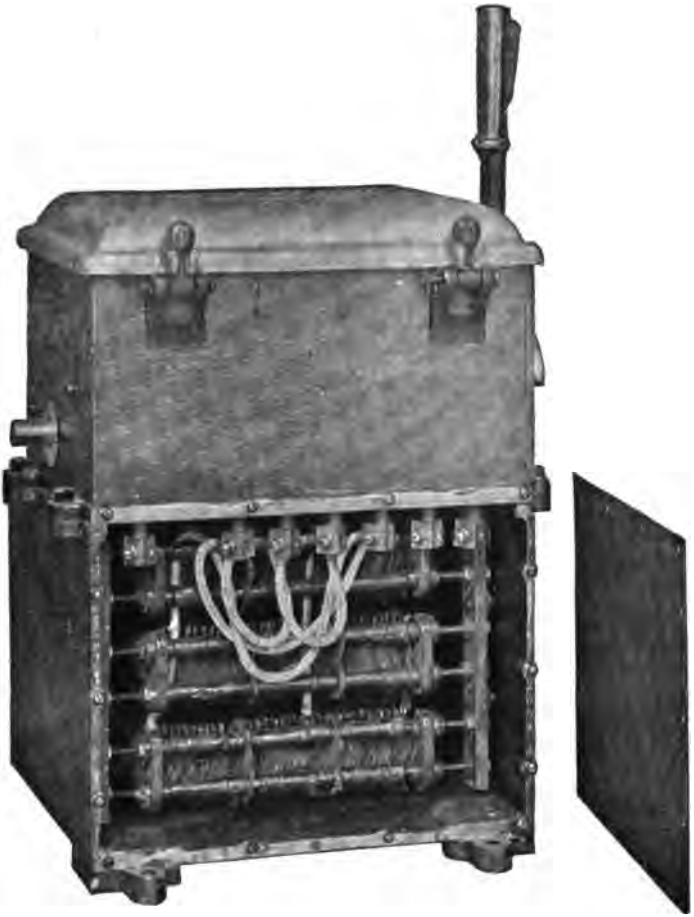


FIG. 176.—Controller for Rammer Motor.

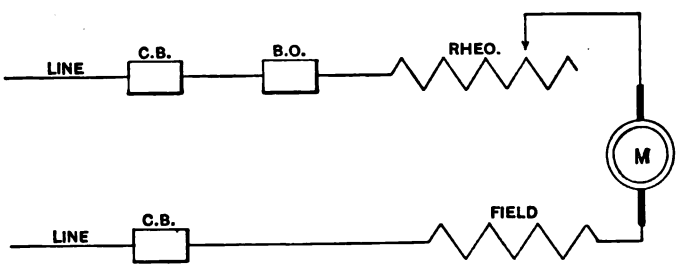


FIG. 177.—Elementary Diagram of Gun-Loading Equipment.

Friction Safety Clutch.—The pinion on the motor shaft is free to revolve on the shaft, except as it is held by the friction between it and the steel disc keyed to the shaft, which is pressed against the pinion by a steel spiral spring. So long as the friction between the composition pinion and the steel disc is sufficient to absorb the torque of the motor, this pinion drives the gear on the rammer, operating it. Whenever for any reason the motor takes an exces-

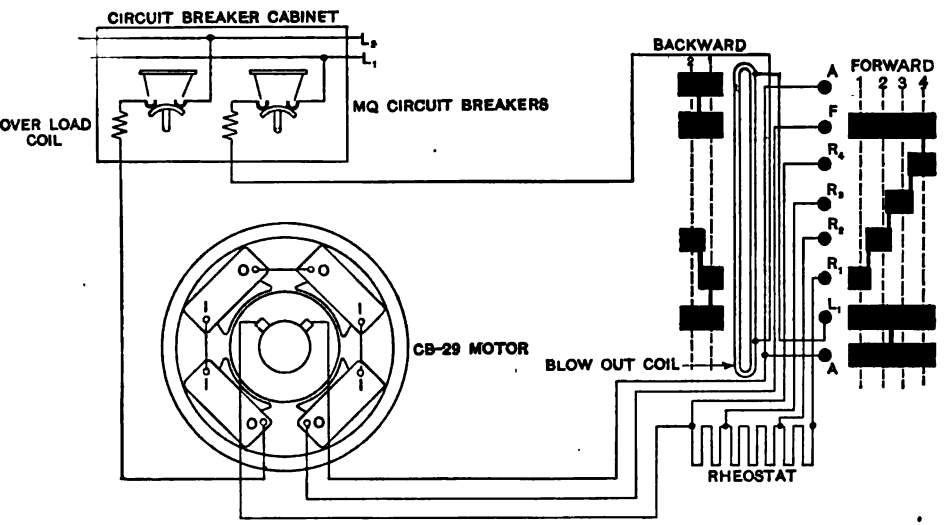


FIG. 178.—Electrical Connections of Gun Rammers. Gen. Elec. Co.

sive current, developing a torque beyond the friction between the pinion and the disc, the armature shaft slips freely in the pinion. The friction between the panel and the disc is regulated by increasing or decreasing compression on the spring, which is done by setting up on the jam nuts on the end of the armature shaft. This clutch is an essential feature of the rammer apparatus, as otherwise very excessive currents might cause damage, or at least blow the fuses when the shell was finally pressed home in the bore of the gun.

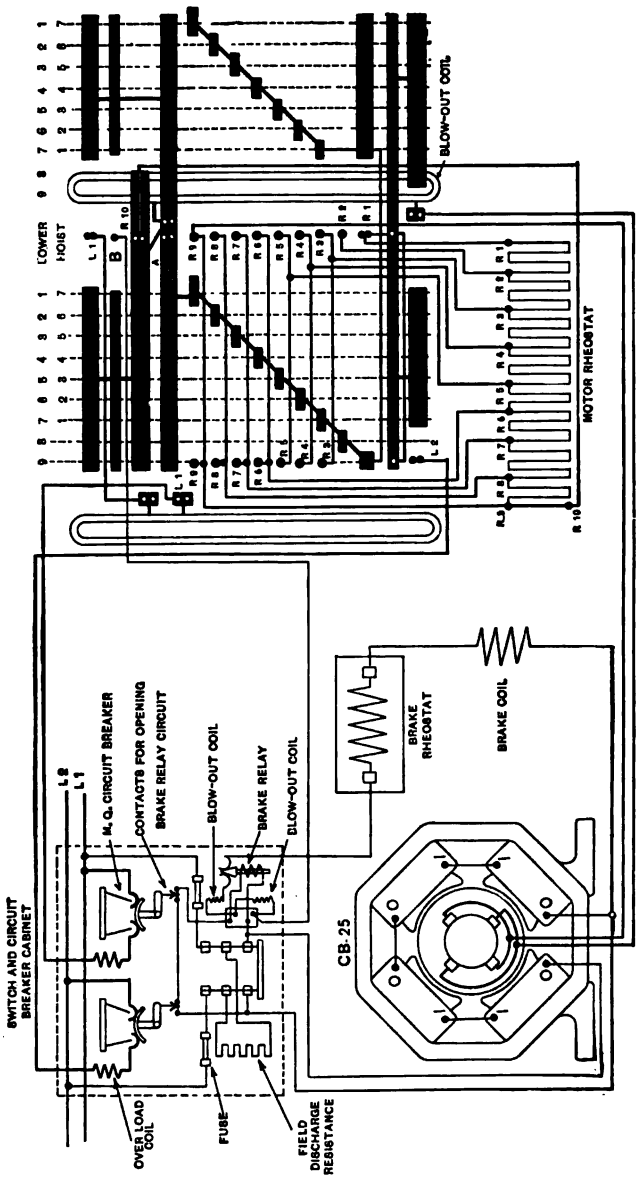


FIG. 179.—Connections for 12-inch Ammunition Hoist. Gen. Elec. Co.

Ammunition Hoists.

These are of three general types, viz., **turret-ammunition hoists, chain-ammunition hoists** and **whip-ammunition hoists.**

Turret-Ammunition Hoists.

The equipment for the latest type of control consists of a shunt motor fitted with disc pattern of brake, controller of the *B* type (electrical braking), motor armature rheostat, and a switch and circuit breaker cabinet.

These are shown in Fig. 179, and the elementary diagram of connections for lowering in Fig. 180. For hoisting, the connections

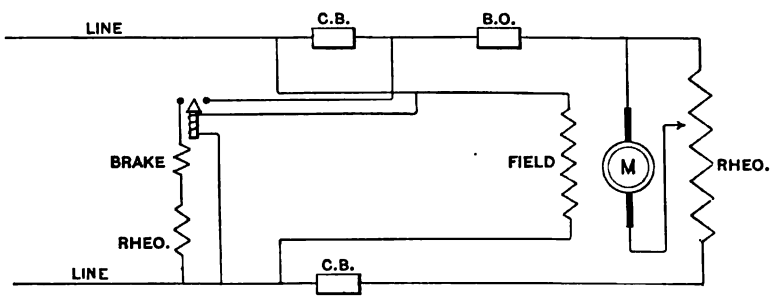


FIG. 180.—Elementary Diagram of Ammunition-Hoist Connections (Lowering).

are the same with the exception that the rheostat is in series with the armature. The system of control is the Day system previously explained.

In the controller the handle is arranged to turn the cylinder through bevel gears; raising the handle directs the current through the motor to hoist the ammunition car and lowering it lowers the car. It is of the type described under the *B* rheostats with the resistance in series with the armature for hoisting and across the line for lowering, and the armature short-circuited when in the "off" position, producing powerful brake effect.

The brake circuit is connected so that it is released when current is on and with a brake relay in parallel with the motor field, so that if the field current fails, the brake circuit is broken and the

brake set. To stop the hoist suddenly, it is only necessary to throw the handle to the *off* position quickly, which immediately opens the circuit and the brake is immediately set. Also, if the main circuit breakers open, due to overload, the relay circuit is broken, which

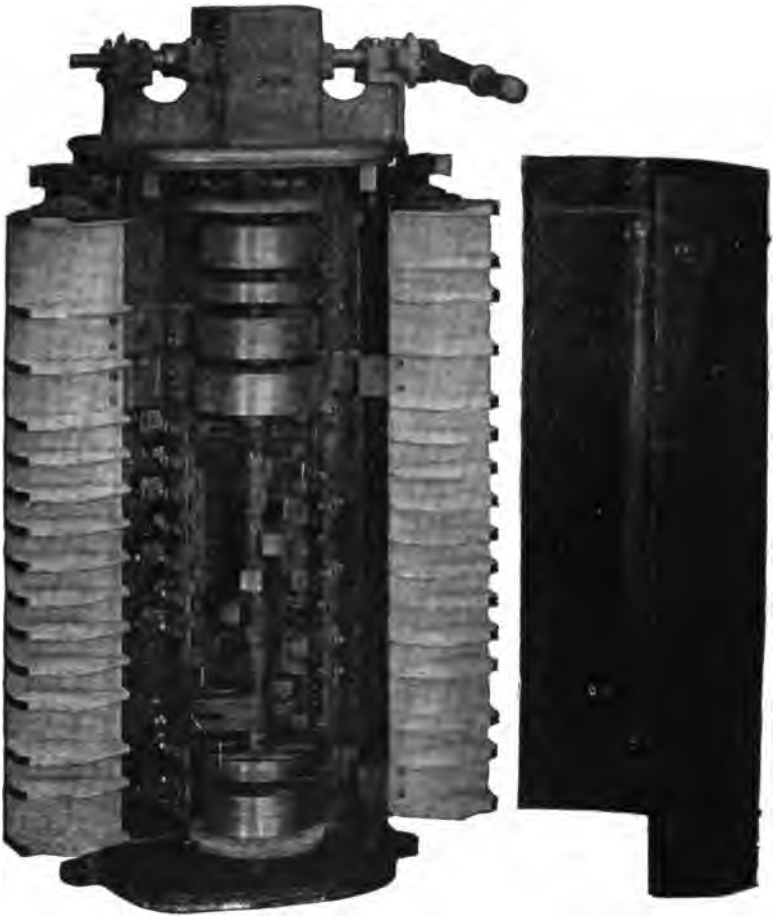


FIG. 181.—12-inch Ammunition-Hoist Controller.

opens the brake circuit and sets the brake. This is shown in Fig. 180.

An open view of a 12-inch turret ammunition-hoist controller is shown in Fig. 181.

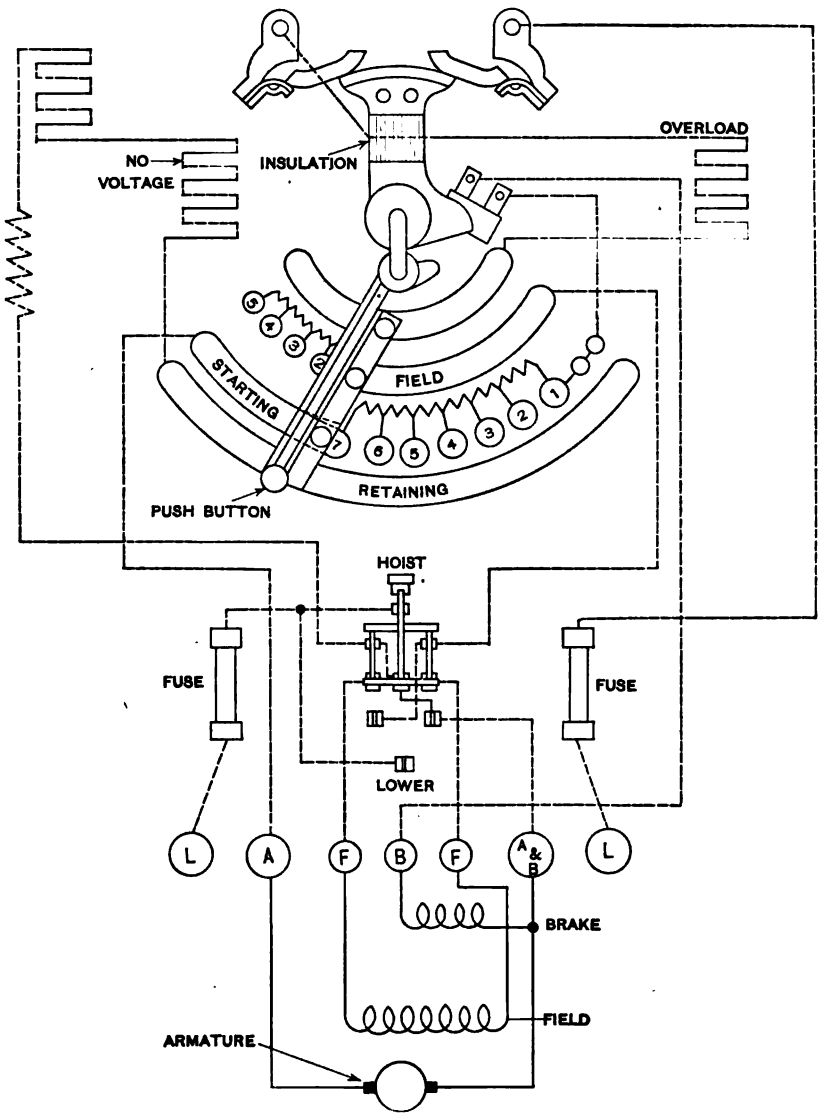


FIG. 182.—Controlling Panel for Chain Hoist. Gen. Elec. Co.

Chain-Ammunition Hoists.

The electrical equipment consists of the **motor** with **solenoid brake** and its **controlling panel.**

The electrical connections are shown in Fig. 182, and the elementary diagram in Fig. 183.

Solenoid Brake.—This is of the solenoid type previously described and consists of a brake wheel on the armature shaft and a leather-lined band operated by a lever and solenoid. The solenoid consists of a coil entirely enclosed in an iron shell, thus completely protecting it from external injury, while allowing it to be easily taken apart for inspection. When current is on the coil, the lever arm is lifted and the brake released, and when current fails the lever arm drops and the brake is set.

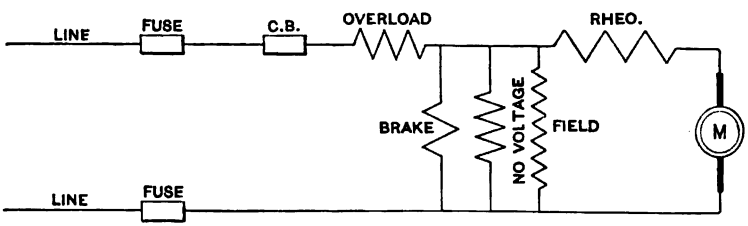


FIG. 183.—Elementary Diagram of Connections of Ammunition Hoist.

From the diagram it is seen that the brake solenoid receives full voltage of the line from the controlling panel when the motor is running with full voltage on the armature.

Mechanical Equipment.—Each hoist consists of a pair of endless chains, traveling over sprocket wheels, and reaching from the point of loading to that of delivery. These chains support between them carriages placed at proper intervals for receiving the ammunition, the whole being driven by an electric motor through a system of gearing.

The armature shaft of the motor is geared to a counter shaft of the hoist which has a pinion on the other end, engaging a gear on a shaft carrying the two sprocket wheels. The continuous chain belts pass over these sprockets and run up to two similar sprockets

in a casting set in the deck at the point of delivery. These chain belts are connected at equal intervals by carriages on which the ammunition boxes are placed. The two bearings of the shaft for the lower sprockets can be moved along an arc of a circle having its center at the center of the counter shaft which is geared to the sprocket shaft. This permits the distance between the upper and lower sprockets to be adjusted to compensate for stretch and wear in the chain. The adjustment is made by means of two adjusting screws, with lock nuts, which push the bearings up or down. When the adjustment is made, the bearings are held in place by a lock nut.

In order to prevent the possibility of the loads overhauling and running the hoist backwards in case the driving mechanism should fail, pawls are provided which allow the carriages to pass up, but will catch and hold them if they move down. When it is desired to lower ammunition, these pawls can be thrown out of action by means of a rod operated from the top of the hoist. This rod runs down the side of the hoist, and when revolved it raises the pawls and turns them back into pockets so that the carriages can descend without engaging them. A hand gear is provided in order that the hoist may still be operated if for any cause the driving motor fails. It consists of a hand crank located at a convenient place near the hoist and connected by an arrangement of sprocket wheels and chain to a clutch on the intermediate shaft. This clutch is operated by a hand lever, moving in the plane of the shaft, and is so constructed that when the lever is moved in one direction, the intermediate shaft is connected to the large motor gear and the hoist is electrically driven; but when the lever is moved in the opposite direction, the intermediate shaft is disconnected from the motor gear and is connected to the sprocket of the hand gear and the hoist is ready for hand drive. When the lever is thrown for hand drive, the intermediate shaft runs freely in the motor gear, and when it is thrown for electric drive, the shaft runs freely in the sprocket wheel of the hand-drive system.

Whip Hoists.

These are generally installed for hoisting ammunition for the secondary battery between decks or bridges, by means of rope whips.

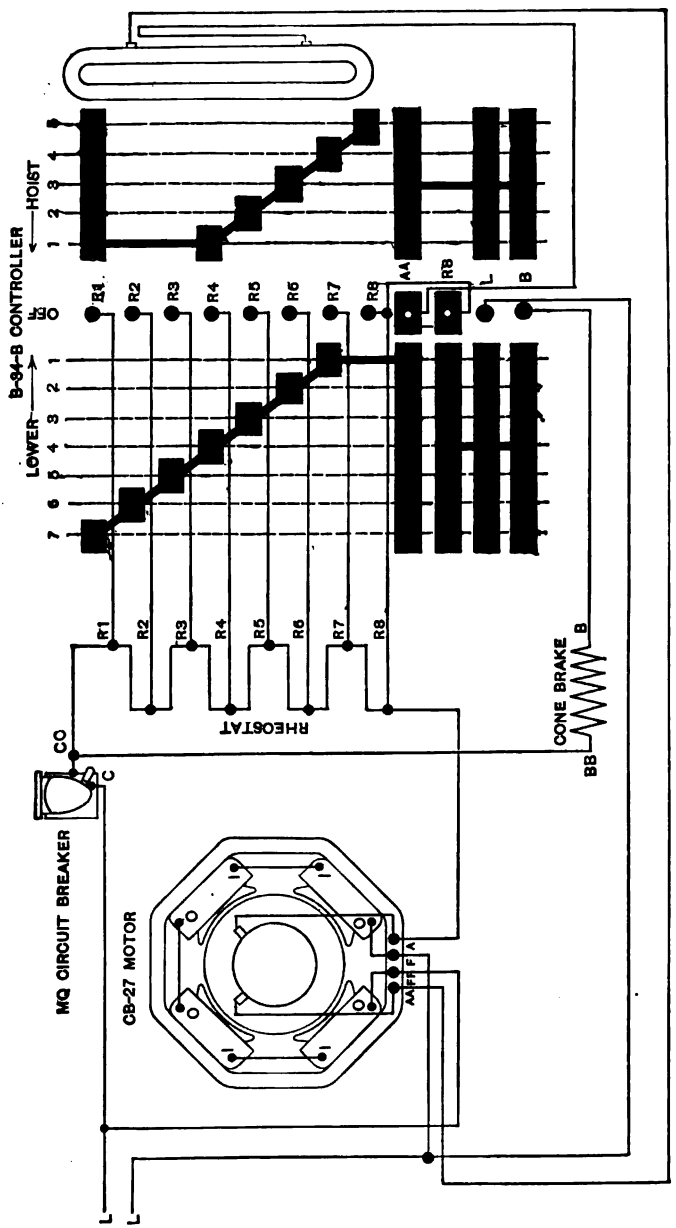


FIG. 184.—Electrical Connections for Whip Hoists. Gen. Elec. Co.

Electrical Equipment.—Each equipment consists of an enclosed **water-proof shunt motor,** having its armature shaft geared to a drum shaft and operated by a **single cylinder controller** and **rheostat.** The diagram of connections is shown in Fig. 184 and the elementary diagram in Fig. 185.

The armature shaft of the motor is fitted with a magnetic cone brake, so constructed that the friction is released as soon as the controller is turned to the hoisting or lowering position, but promptly operates as soon as the controller is turned to the *off* position, or current fails through any cause.

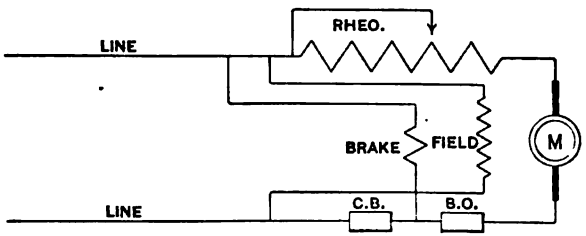


FIG. 185.—Elementary Diagram of Connections of Whip Hoist.

The controller is of the *B* type, and in lowering produces the braking effect of the Day system of control. The armature is also short-circuited on the *off* position of the controller.

Boat Cranes.

The electrical equipment of boat cranes present differences in their details but the electrical principles are the same. It consists generally of two **iron-clad enclosed series motors,** one for hoisting and one for revolving. In some installations there are two **separate controllers,** each in a separate casing, one for each motor, with **separate circuit breakers** mounted in separate boxes operated from the outside; and in others the two controllers and circuit breakers are all mounted in one case.

The electrical connections are shown in Fig. 186 and the elementary diagram of connections in Fig. 187.

The controllers are the *R* type, the rheostat is of the **pressed-ribbon** type, and the circuit breakers of the *MQ* type.

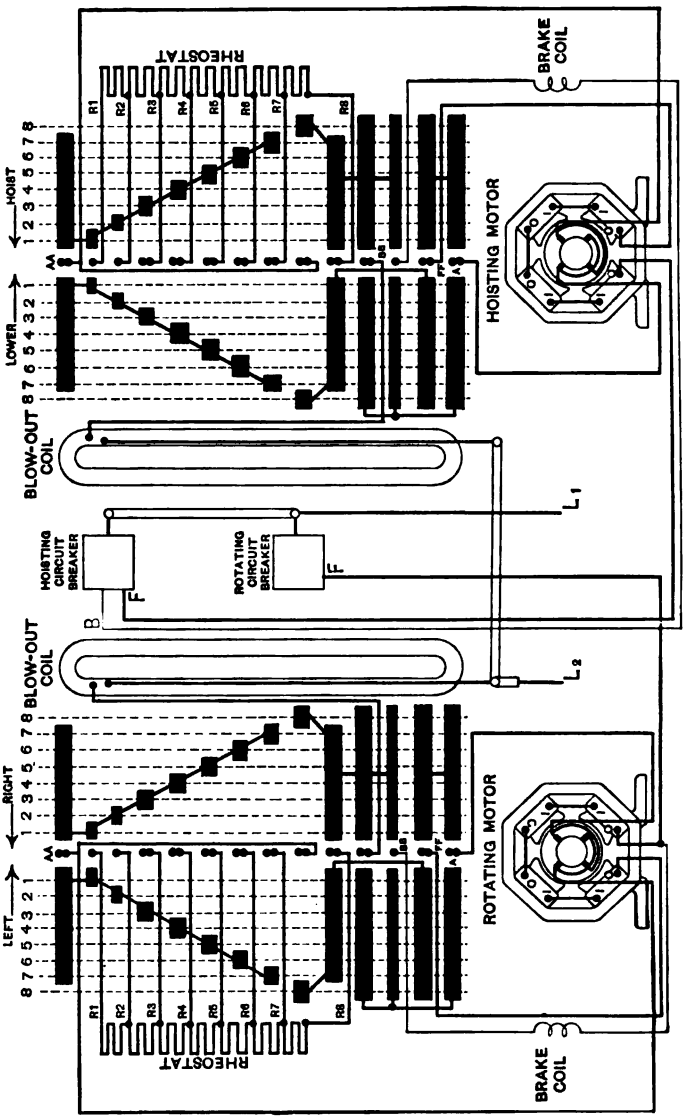


FIG. 186.—Electrical Connections of Boat-Crane Circuits.

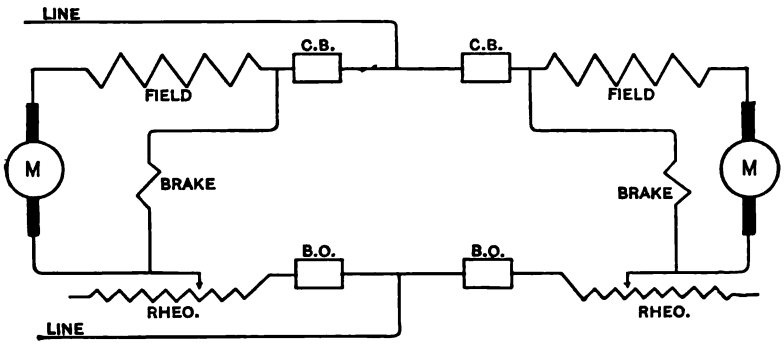


FIG. 187.—Elementary Diagram of Connections of Boat Cranes.

A view of a controller used with boat cranes is shown in Fig. 188.

The **brake** is of the **disc** type and is contained in a cast-steel frame, arranged to be bolted to the same foundation as the motor. Within the frame and surrounding the extension of the armature shaft, a series of discs are arranged, alternate discs being keyed to the shaft and the intervening discs being keyed to the frame. Several spiral springs serve to press the discs together and produce a powerful braking effect upon the armature shaft through the friction between the revolving and stationary discs. A solenoid coil is provided which opposes the action of the springs, compressing them when the current is on and thus releasing the brake when the current fails from any cause whatever.

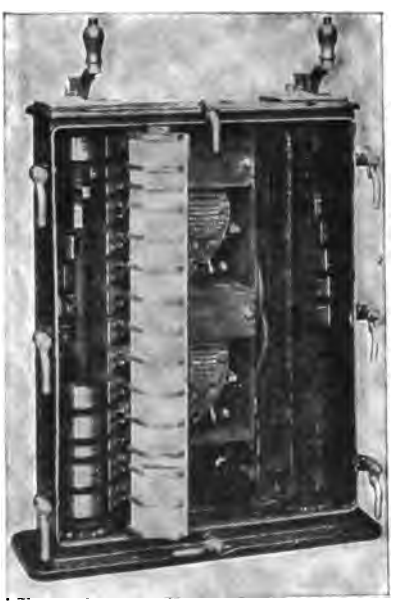


FIG. 188.—R-62 Controller Used on Boat Cranes.

Mechanical Connections.—For hoisting, a pinion on the hoisting motor armature shaft meshes with a gear wheel on a worm shaft, the worm wheel being secured to the drum shaft, over which passes the wire cable for hoisting.

For revolving, a pinion on the revolving motor armature shaft meshes with a gear wheel on a worm shaft. The worm wheel with which this engages is secured to a vertical shaft and on the bottom of this a pinion is secured which meshes with a circular stationary rack.

Automatic Brake.—In the addition to the magnetic disc brake with which the hoisting motor is held, there is generally fitted an automatic mechanical brake.

The automatic brake is fitted on the worm shaft from which the hoisting drum is operated, and it in turn is operated through a gear wheel by a pinion on the armature shaft of the hoisting motor. On this worm shaft there is keyed a bushing in the shape of a sleeve with a flange on the end toward the worm. This sleeve is threaded on its outer circumference on the side away from the worm. A bushed ratchet wheel fits around this sleeve and against the side of the flange away from the worm. A fiber disc washer is inserted between the ratchet wheel and the flange of the bushing. There are two pawls secured to the framing of the crane entirely independent of the hoisting gear, set to engage the ratchet teeth alternately. A second fiber washer is fitted on the outboard side of the ratchet wheel.

The gear wheel which is driven by the motor pinion is threaded to work on the screw on the outer surface of the bushing above mentioned. It is thus seen that the ratchet wheel works between the flange of this bushing and the face of the gear wheel which is towards the worm.

A clutch which can be laterally adjusted by means of two locking nuts is keyed on to the end of the worm shaft.

The operation of this brake is as follows:

Hoisting.—In hoisting, the gear wheel is driven by the motor pinion and chases along the threaded bushing until it comes up tight against the fiber washers, the ratchet wheel and the flange on the end of the bushing. These finally become squeezed up tight

and all run together thus operating the worm shaft and hoisting the load. In this direction the ratchet pawls are not operative, sliding over the teeth of the ratchet wheel.

Lowering.—In lowering, as soon as the pinion of the armature shaft starts to drive the gear wheel, the ratchet pawls hold the ratchet wheel and the gear unscrews along the bushing, releasing the friction between the gear, the ratchet wheel and the flange of the bushing. If the load is then not sufficient to overhaul (and with the worm gear it will always be necessary to start the load in the lowering direction), the gear wheel unscrews until it comes against the clutch on the end of the shaft, which makes a positive connection and starts the load in the lowering direction. If, in lowering, the speed of the worm shaft becomes greater than the speed of the gear wheel, due to the load tending to overhaul the motor, this gear again screws along the bushing until it brings up against the fiber washers and the now fixed ratchet wheel. The friction between this ratchet wheel, the gear and the flange of the bushing checks the speed of the worm shaft until such time as the speed of the worm shaft has been reduced below the speed of the gear wheel, when the gear again unscrews itself and releases the friction. This setting up and unscrewing on the friction discs by the gear wheel will continue if the load overhauls the motor. But if this is not the case, and the motor keeps ahead of the load, the lowering is done by the motor which is driven from the gear and the clutch on the end of the shaft.

Deck Winches.

These are used on the upper and uncovered decks, forecastle and quarterdeck for general deck use, hoisting boats, hoisting on board stores, ammunition, etc., and in general use for connection with booms for coaling ship. They must of necessity be entirely water and dust tight and both electrically and mechanically strong.

The electrical equipment consists of a **compound motor**, an **R controller, pressed-ribbon rheostat, MQ circuit breaker** and a **reversing cylinder.**

The electrical connections are shown in Fig. 189 where the function of the controller is readily seen. For reversing, there is a

separate cylindrical switch, shown on the right, which reverses the armature current while allowing the field current to remain in the same direction.

The controller simply makes connection between the mains and the armature and field, and controls the starting resistance. Reversal is accomplished by turning the reversing cylinder which reverses the direction of the armature current.

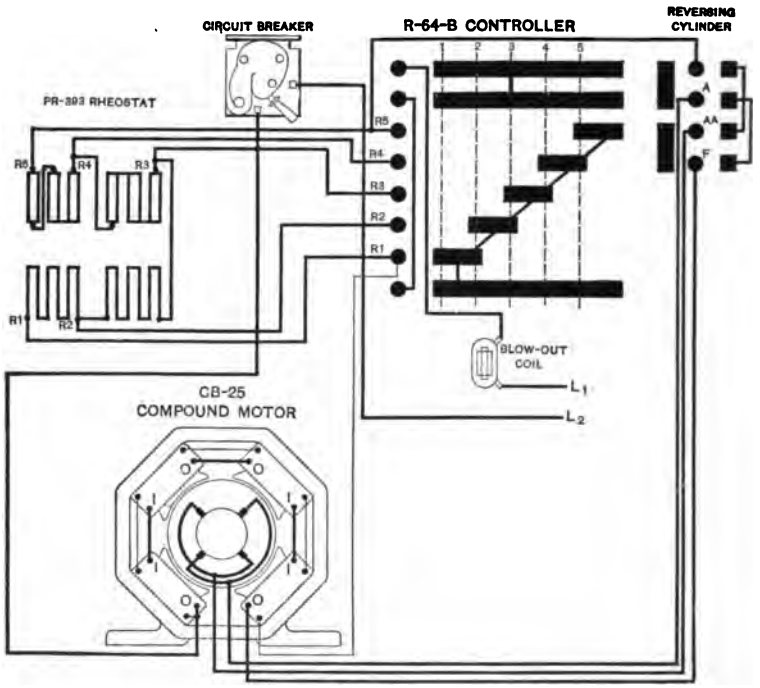


FIG. 189.—Deck Winch Electrical Connections. Gen. Elec. Co.

An interior view of the controller is shown in Fig. 190.

Mechanical Connections.—The motor is mounted on the foundation of the winch and is connected to the driving shaft by gear wheels, one on the armature shaft and the other on the driving shaft. The driving shaft has a drum at each end, and the shaft is fitted with a clutch by which one of the drums may be thrown out.

A band brake is fitted on the armature shaft, the band lined with wood encloses the wheel and is set by the foot of the operator.

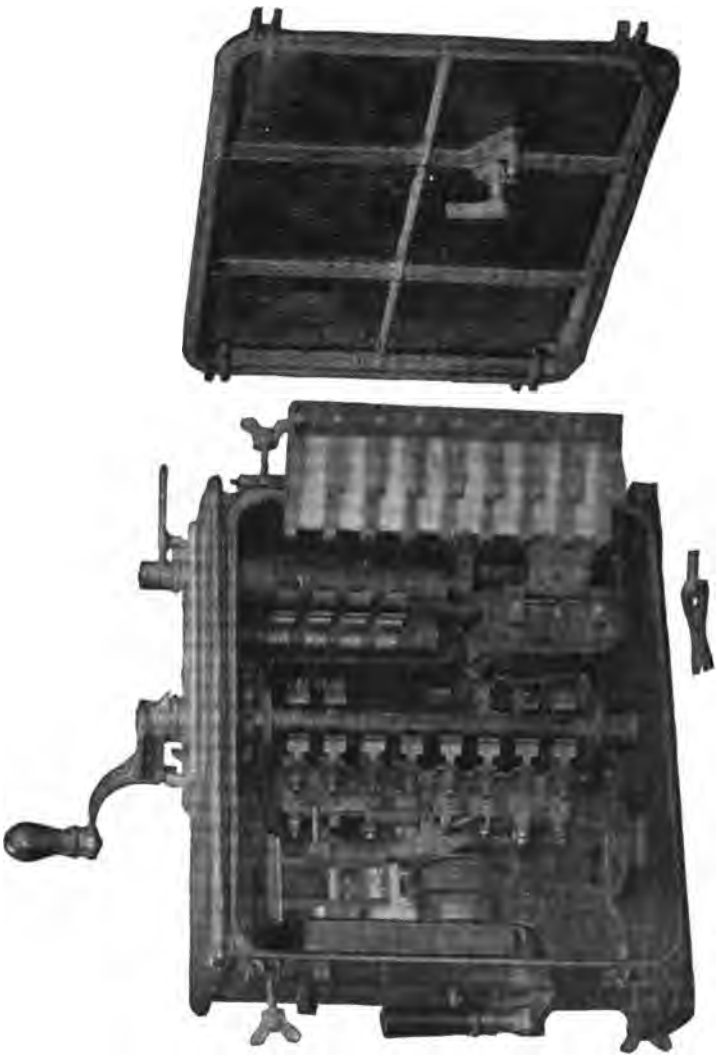


FIG. 190.—Controller for Deck Winch. Gen. Elec. Co.

Ventilation Equipment.

The ventilation system installed on vessels of the navy may be generally divided into two classes, *portable* and *fixed.*

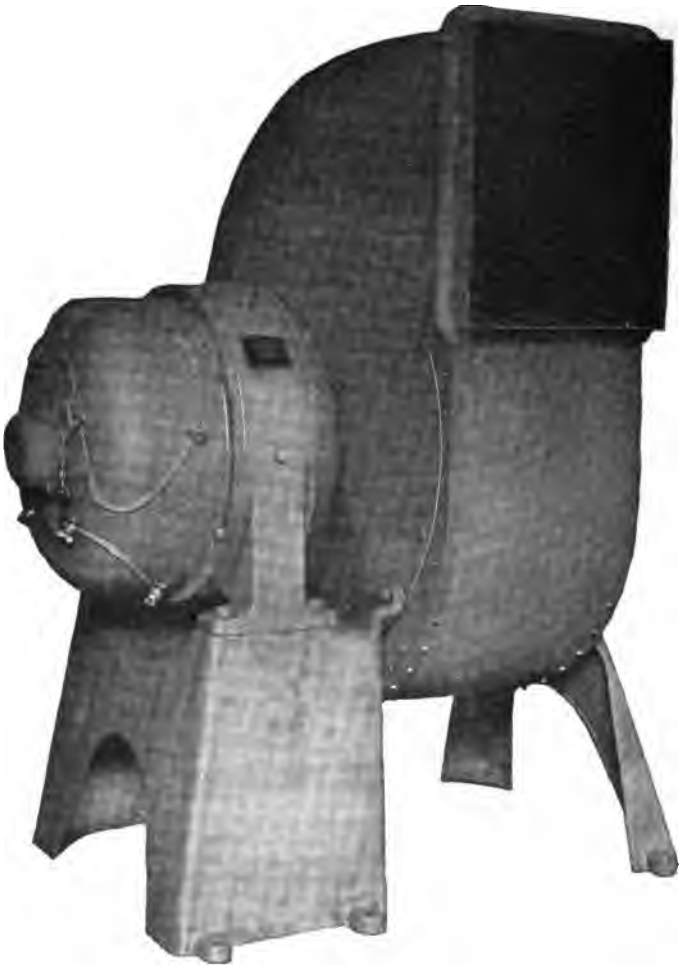


FIG. 191.—Enclosed Motor and Fan.

Portable ventilating fans include those of ¼ horsepower for use in ventilating closed spaces that may be occasionally used, princi-

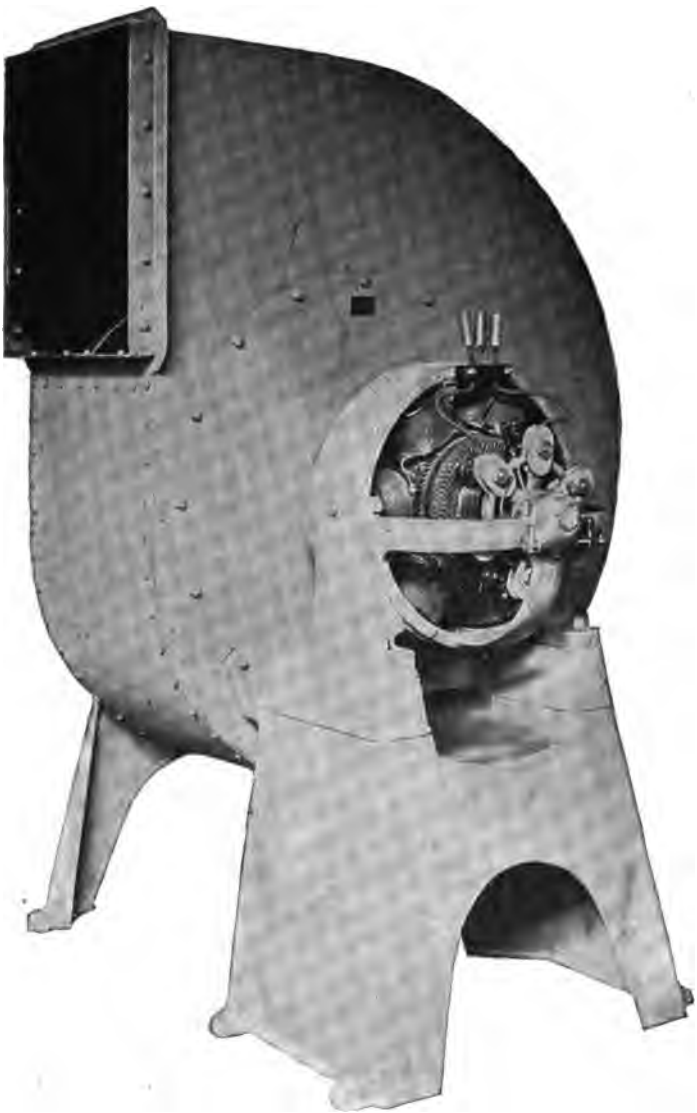


FIG. 192.—Open Motor and Fan.

pally the double bottoms and holds and for this purpose are fitted with flexible tubing to the delivery side. They also include the $\frac{1}{6}$ and $\frac{1}{12}$ horsepower fans for ventilation in state-rooms and small isolated store-rooms, and are generally of the bracket and pedestal type.

For the fixed ventilation units, different combinations of fans and motors have been installed, the fans being made by B. F. Sturtevant & Co. and General Electric Company, and motors by The Sturtevant Company, Holtzer-Cabot Company, and General Electric Company.

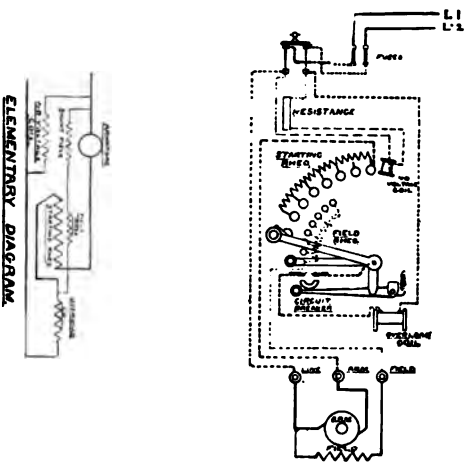


FIG. 193.—Controlling Panel for Ventilating Blowers.

The fans generally are of the monogram or steel-plate type, the former being used for fans requiring small power. The steel-plate fans are designated in size by their diameter. They are built up of steel plate and angle bar and the fan wheels are of steel with brass hubs.

The motors are either enclosed or open, depending on their location and all are directly connected to the fan shafts.

Views of ventilating units furnished by the General Electric Company, showing enclosed and open motors directly connected to the fans are shown in Figs. 191 and 192.

Controlling Panels for Ventilating Sets.

A general type of controlling panel is similar to that used for chain-ammunition hoists, but for those requiring a varying speed, obtained by changing the resistance of the field circuit a form shown in Fig. 144 is used.

This latter requirement is also met by a form of controlling panel, shown diagrammatically in Fig. 193.

Electrical Connections of Desk and Bracket Fans.—These small motors of $\frac{1}{8}$ and $\frac{1}{12}$ horsepower are **series wound** and fitted with three speed contacts, effected by varying the resistance in series with the armature and field.

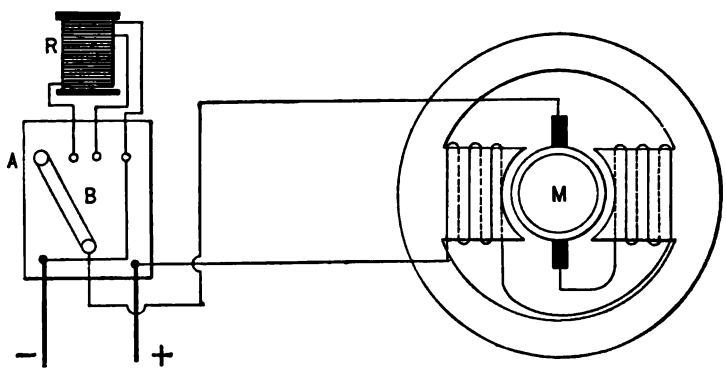


FIG. 194.—Connections of Desk Fans.

The connections of the controlling and starting switch with the rheostat is shown in Fig. 194.

The connection board *B* is of porcelain mounted in the base of the bracket or stand. *A* is the starting arm, moving over the contact pieces shown, which are connected to different portions of the rheostat, or starting resistance *R*. On the first contact as shown, the circuit is open, and on moving *A* to the right on the first contact, the circuit is established from the supply main to the motor field, then through the armature, back to the pivot contact of *A*, then through all of the resistance *R*, back to the other main. On the second contact, more resistance is cut out and on the last contact *R* is short-circuited when the motor is running at full speed.

Water-Tight Door and Hatch Equipment.

The present practice of operating water-tight doors and hatches is through the agency of electric motors, and each hatch or door is operated by its own separate motor. The power is conveyed from each motor through gearing to the door or hatch; for vertical doors a worm engages directly with a worm rack on the door, and for horizontal doors, a worm engages a worm wheel actuating a shaft carrying pinions which engage with racks on the doors.

The motor with its controller is mounted in a power box, and in addition to the connections to each motor, there is an auxiliary circuit leading to an emergency station or stations, in the chart-house, or on the bridge, which controls a device for showing automatically whether the door is open or shut. The emergency station is fitted with a switch by which current is sent through all the operating motors, so that the doors or hatches may be closed almost simultaneously, current being on four or five motors at a time.

The **controller** is a somewhat complicated affair and has three separate functions: (1) to allow each door or hatch to be opened or closed by local working, (2) to allow each to be operated practically at the same time from the emergency station, (3) to allow each or any door or hatch to be operated locally when closed from the emergency station. In the last operation, a door or hatch that has been closed from the emergency station may be opened locally, but it will immediately close automatically if the emergency switch is closed. When each door or hatch is completely closed or meets with an unyielding resistance, a limit switch in the controller acts to cut off the current to the motor for closing, but leaves current on for operating the door for opening.

Wiring Diagram.—The general scheme of wiring is shown in Fig. 195.

L_1 and L_2 are power mains with connections to the main switch-board or distribution boards. The motors M are compound wound, bipolar and iron-clad type, controlled each by its controller marked C. The emergency switch is marked E, and when this is turned in the direction of the arrow, circuit is completed through the right-hand positive connection from the power mains to and through the

switch, through the solenoids, *S*, and to the negative main. The energizing of the solenoid attracts the core which closes the emergency switch in the controller when current is sent through each motor by its connection to the power mains. When each motor has closed its own door, the motor can still be controlled for opening by operating the local switch at the controller, but on releasing it, the motor will immediately operate to close the door as long as the emergency switch is closed.

As each door is closed, circuit is made by means of the auxiliary contacts, *A*, through a lamp, *L*, at the emergency station which

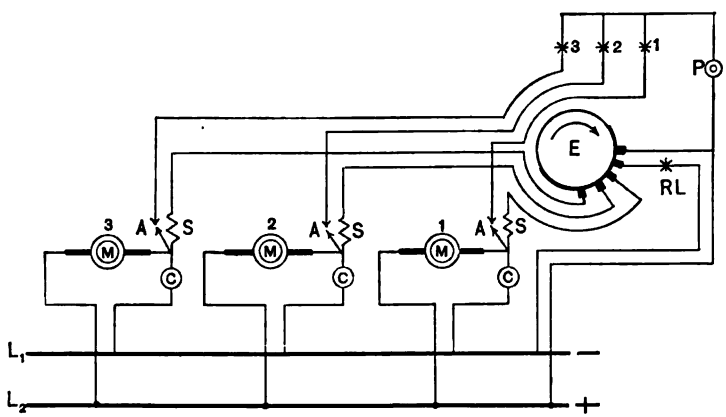


FIG. 195.—Wiring Diagram of Motors.

illuminates a dial showing the number of the door. After the emergency switch has been turned, the operator can press the push button *P* and can tell at a glance which doors are not closed. These lamps are also lit when each door is locally closed and the button *P* is closed. This button is normally kept open, but to tell what doors in the ship are open or shut, it is only necessary to close the contact *P*.

In order to make sure that current is on, there is a tell-tale red lamp, marked *RL* and so connected that as soon as current goes through the first solenoid, the lamp will glow and will continue to burn until the emergency switch is turned to the *off* position.

Miscellaneous Electric Equipments.

In addition to the general electric equipments described in the preceding pages, there are many examples of individual machines and tools driven by electric motors. In all such cases, as machine-shop tools, laundry machines, and such individual electric-driven machines as dishwashers, potato peelers, dough mixers, ice-cream freezers, printing presses, pumps, air compressors, etc., the power required is small, and the equipment usually consists of the motor, either directly connected to the machine, or through gearing or belting, and a starting panel of the general characteristics already described. With the help of previously described equipments, these individual electric equipments should present no difficulties either in principle or in operation. Although the controllers and starting panels may be of different construction, their operation should be readily understood.

FIG. 196.—Type C. R. Controlling Panel. Gen. Elec. Co.

A general form of controlling panels for use with motors of less than 3 horsepower is shown in Fig. 196.

CHAPTER XIX.

PRINCIPLES OF ALTERNATING CURRENTS.

All electric generators induce alternating currents in their armature windings, due to the conductors passing alternately magnetic poles of opposite polarity; in which operation the E. M. F. induced by the cutting of the lines of force, is reversed as the conductor passes from pole to pole. One of the chief differences between continuous and alternating current generators is in the method of

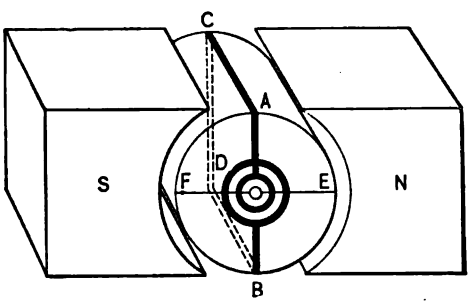


FIG. 197.—Coil in Magnetic Field.

collecting the current from the armature conductors; the continuous current generator requiring a commutator to rectify the alternating currents of the armature conductors into current in one direction in the external circuit, while in an alternator the currents are collected by rings and the currents in the external circuit are in the same direction as those in the armature conductors.

Variation of E. M. F.—A reference to Fig. 197 will show a rectangular coil *ABCD* at right angles to the magnetic field between the poles *N* and *S*.

The E. M. F. generated by a coil moving in a magnetic field is numerically equal to the *rate* at which it cuts the lines of force. The rate of cutting varies with the position of the coil as it moves around its center of revolution *O*. It must be remembered that

the active cutting portions of the coil are *AC* and *BD*, the remaining portions *CD* and *AB* simply completing the closed circuit.

In the position of the coil shown by *AB*, the rate of cutting of lines of force is least, as at that position, the motion of the conductor *AC* is parallel to the lines of force, but in a position 90° from *AB*, as at *EF*, the rate of cutting is greatest, as at this position, the motion of the conductor is perpendicular to the lines of force.

If *V* represents the velocity of the coil in its revolution, the velocity at any instant is the linear velocity in a tangent to the circle of revolution at that point. In Fig. 197 the velocity at the point *E* is represented by the velocity in the tangent at that point, *V*, shown in Fig. 198. As the generated E. M. F. is greatest at that point, the maximum E. M. F. may also be represented by *V*, for the E. M. F. is numerically equal to the velocity, or rate of cutting. The rate of cutting at any point is proportional to the component of *V* that is perpendicular to the lines of force, that is, the vertical component, and at any point *H*, the vertical component is *V* cos θ', or *V* sin θ, where θ is the angle turned through from the initial or zero position, and therefore, the E. M. F. at any point is equal to *V* sin θ, where *V* is the maximum E. M. F.

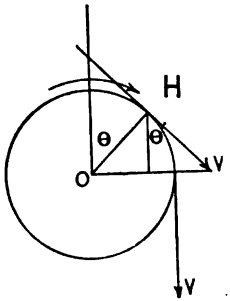


FIG. 198.

A curve of variation of E. M. F. is shown in Fig. 199, where for each value of θ measured horizontally in degrees from 0°, ordinates are set up vertically to represent *V* sin θ, the E. M. F. for that position of the conductor, and a curve drawn through the points so obtained.

This is a **sine curve** and the change of direction of the E. M. F. which occurs when the conductor begins to cut the lines in the reverse direction is shown by the curve crossing the zero line. E. M. F's. above the line are called *positive* and those below *negative*.

Definitions.—The time taken by the E. M. F. to pass through a complete series of changes such as represented in Fig. 199 is called a **period**, and the complete operation is called a **cycle.**

The **frequency** is the number of periods, or number of cycles per second.

The **amplitude** is the maximum value of the variable E. M. F.

The **phase** of any point is measured by the angle swept over by the point from the zero position. Thus the phase at position of maximum positive E. M. F. is 90°, maximum negative E. M. F. is 270°, at minimum E. M. F. it is 0°, 180° or 360°. The phase may also be measured in terms of a complete cycle, thus the phase at 90° is $\frac{1}{4}$, at 180° is $\frac{1}{2}$, at 360° is 1, etc.

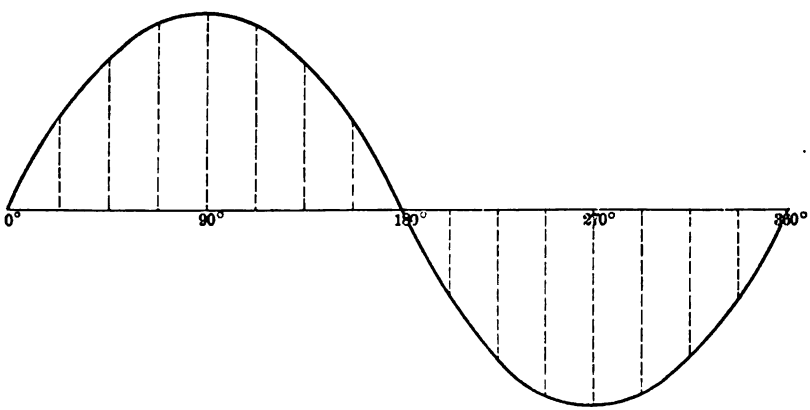


FIG. 199.—Curve of E. M. F.

Example.

A bipolar alternator gives a maximum of 500 volts with a frequency of 100, what will be the phase and voltage $3\frac{1}{3}$ seconds after starting from the point of minimum E. M. F.?

In $3\frac{1}{3}$ seconds, a coil will have passed through $3\frac{1}{3}$ x 100 x 360 degrees, or 333 complete cycles and $\frac{1}{3}$ of a cycle, and the coil will be in phase $360° \div 3 = 120°$.

The value of the E. M. F. at phase 120° will be $V \sin\theta$ or $500 \times \sin 120° = 433$ volts.

Effect of Increase in Number of Poles and Conductors.—The frequency of the alternations depends upon both the speed with which the conductors are moved and upon the number of the alternate poles under which the alternations take place. In the case of

a multipolar machine a period will be the time occupied for a conductor to move from one pole to a similar position under the nearest pole of the same polarity. In a 10-pole alternator there will be five periods per revolution, or the frequency per revolution will be five. In general, if

n = number of revolutions per second,
P = number of pairs of poles,
n' = frequency.

Then

$$n' = \frac{n \times P}{60}.$$

In order to increase the E. M. F. generated in a machine, the number of conductors must be increased, and the total E. M. F. generated in an armature composed of a great number of conductors will be equal to the sum of the voltages in the individual conductors if (1) *the conductors under opposite poles are joined alternately at the front and back of the armature so that the E. M. F. induced in the successive conductors in opposite directions is made to act in the same sequence in the complete winding,* and (2) *if the conductors passing under a pole at any time are sufficiently close together to enter and leave the pole at nearly the same time.*

Self-Induction in an Alternating Current.

An alternating current is always accompanied by a *changing* magnetic field, the rapidity of the change being dependent on the number of the alternations. This rapidly changing field reacts on the current producing it, and has the same effect as though the conductor were moved through a field of as many lines of force as are produced by the current. The effect of the changing field on the conductor is to generate an E. M. F. called the *E. M. F. of self-induction,* which acts to oppose any change in the current. If the current is increasing, this self-induction tends to oppose the increase and if decreasing, it opposes the decrease.

This E. M. F. of self-induction, sometimes called *back* or *counter* E. M. F. is dependent on the rate at which the magnetic field due to the current changes, and hence is proportional to the rate at which the current itself changes and not directly on the current or on the number of lines of force.

Curves of Current and Rate of Change of Current.—Fig. 199 shows that the induced E. M. F. in an alternating current and consequently the current produced thereby is proportional to the sine of the angle through which the conductor has moved, and consequently the rate of change of current is proportional to the differential of the sine or is equal to the cosine of the angle in radians. Fig. 200 shows curve *I* plotted as a **current curve,** and *II,* a **rate of change of current curve.**

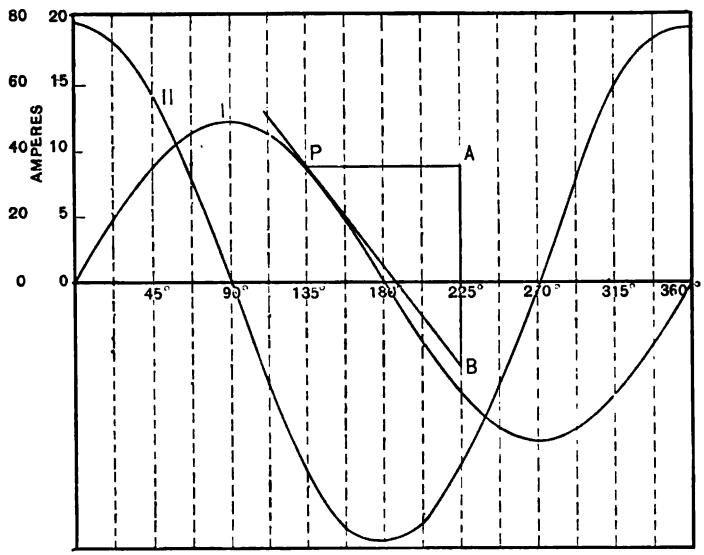


FIG. 200.—Curves of Current and Rate of Change of Current.

Curve *I* is plotted from the equation $y = C \sin x$. Curve *II* is plotted from the rate of change of curve *I*. The rate of change of the sine of an angle is equal to its cosine when measured in radians. As there are 2π radians in 360° or one cycle, the rate of change per cycle is 2π times the cosine of the angle. The equation for plotting curve *II* then becomes $y' = 2\pi C \cos x$, and the ordinates are plotted as currents and the abscissæ as angles. The maximum value of the rate of change of current occurs when $x = 0°$, for then $y = 2\pi C$ and the maximum ordinate is 6.3 times

the maximum value of C. In the example chosen, the maximum value of C is 12 amperes, and the maximum value of the rate of change of current is $6.3 \times 12 = 75.6$ amperes. For convenience in plotting, the scale of curve *II* is taken four times as great as curve *I*.

It will be noticed that the minimum value of the rate of change of current occurs when $x = 90°$, for then $y' = 2\pi \cos 90° = 0$. The above considerations show that the curve of rate of change of current differs in phase by $\frac{1}{4}$ of a period from the current curve, and that it is in advance in phase by that amount.

Curve *II* could be geometrically plotted as follows: From any point P on the current curve draw a tangent PB and from P lay off a horizontal distance PA equal to the length of $\frac{1}{4}$ cycle and draw a vertical line from A till it meets the tangent at B, then the distance AB is the ordinate on the rate of change of current curve for $\frac{1}{4}$ cycle; and for a curve for a whole cycle, such as *II*, the ordinate would be a distance four times as great. This ordinate would be a point on curve *II* corresponding to the phase of the point P.

If the current passes through n cycles per second, the maximum value of the rate of change per second is $2\pi nC$.

The **coefficient of self-induction** is equal to the E. M. F. induced by a change of one ampere per second, and if

$E =$ E. M. F. of self-induction
$L =$ coefficient of self-induction

we may write, when the current is changing at the rate of one ampere per second

$$E = L.$$

If the ordinates of curve *II* are multiplied by n, it would be a curve of $2\pi nC$, and if the current changes at the rate of $2\pi nC$ amperes per second, the induced E. M. F. of self-induction is

$$E = 2\pi nCL. \qquad (a)$$

From a consideration of the above it is shown that when an alternating current is flowing, it gives rise to a back E. M. F. opposing the change of current, and to overcome this back E. M. F. an additional E. M. F. determined by equation (a) must be applied.

However, from the fact that the two curves of E. M. F. differ in phase, not all of the E found from equation (a) is necessary, but it offers a means of determining what the real applied E. M. F. must be in order to produce a certain current.

Curve of Applied E. M. F.

Suppose it is required to find the applied E. M. F. necessary to maintain a maximum current of 10 amperes in a resistance of 1.5 ohms in a circuit with a self-induction of .005 henry. The alternator has 12 poles with a speed of 1200 revolutions per minute.

There are now two E. M. F's. to be considered: first, that necessary to supply 10 amperes in a resistance of 1.5 ohms, which is the same E. M. F. that would be required in a continuous current; and, second, that necessary to overcome the back E. M. F. due to self-induction. The current curve as plotted is marked C in Fig. 201.

The *resistance E. M. F.*, as it is called, can be plotted to any convenient scale, by multiplying the values of the current at any instant by the resistance of the circuit. Thus the maximum value of the resistance E. M. F. is, for the example cited, $10 \times 1.5 = 15$ volts. This is shown plotted as a curve of sines in Fig. 201, marked E_1.

The curve due to the change of current, or, what is the same thing, the curve of back or *inductance E. M. F.* can now be plotted on the same scale, from the equation $E = 2\pi nLC$, remembering that the curve of resistance E. M. F. is $\frac{1}{4}$ period in advance of the curve of back E. M. F.

The frequency is $\frac{12}{2} \times \frac{1200}{60} = 120$, and the maximum value of E is $2\pi \times 120 \times .005 \times 10 = 38.8$ volts.

The alternator must supply a voltage equivalent to both of the E. M. F's. if the condition required is to be maintained, and at any instant, the applied E. M. F. must be equal to the sum of the resistance and inductance E. M. F's. at that instant. Curve E_3 is plotted by adding together *algebraically* the ordinates of the two curves E_1 and E_2. In the example, the greater portion of the applied E. M. F. is needed to overcome the inductance, but where the inductance is small, the greater part might be necessary to overcome the resistance.

It is seen that the required E. M. F. is not the arithmetical sum of the two E. M. F's. arising from the fact that the two E. M. F's. are not in the same phase.

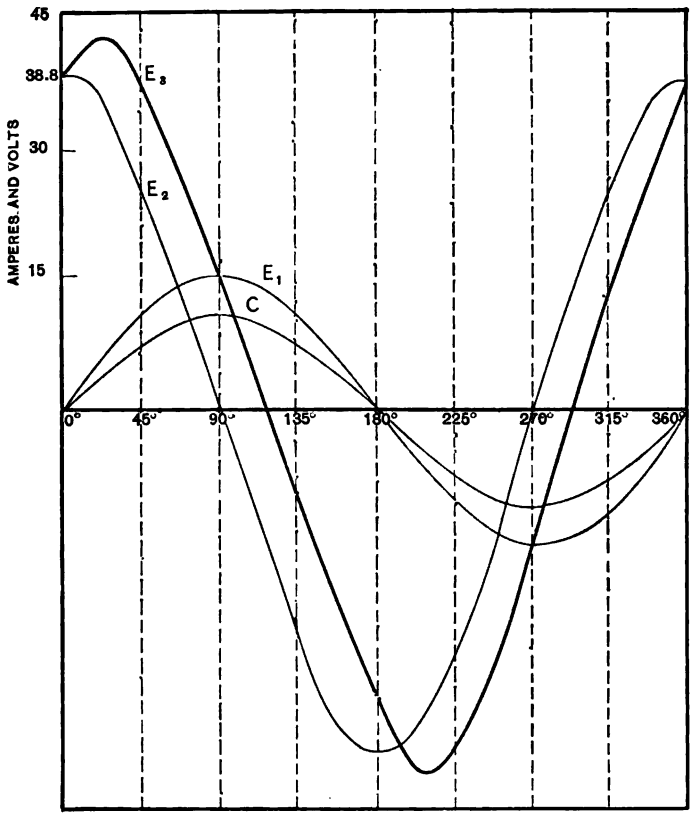


FIG. 201.—Curves of E. M. F. and Resultant E. M. F.

Angle of Lag and Lead.—It will be noted that the curves E_3 and C are not in phase with one another, the difference in phase being measured on the horizontal scale between the points at which they pass through their zero values. If the current curve passes through its zero value at an angle greater than the total E. M. F. curve does, the current is said to *lag* by an amount equal to the

angle of lag, and if the opposite is the case, the current is said to *lead* by an amount equal to the **angle of lead.** Inductance always causes an angle of lag which depends on the nature of the resistances and other apparatus in circuit.

Graphic Representation of Alternating Currents.

The two curves, C and E_3, in Fig. 201, show the changes undergone by the applied E. M. F. and resulting current in one cycle, or in one alternation, and for any given value of E. M. F. the resulting current can be found. From the fact that the two curves differ in phase, the maximum current does not occur at the same time as the maximum E. M. F. To find the current corresponding to maximum E. M. F. it is only necessary to draw an ordinate through the position of maximum E. M. F. and the portion of this ordinate common to the current curve will be the desired value. Thus, in Fig. 201, the desired current is about 5.5 amperes.

Although the varying E. M. F's. and currents can be well represented by curves, such as shown in Fig. 201, yet the process of plotting is tedious, and another method of plotting by right lines, called **vector diagrams,** and which will show all the varying quantities, has been devised.

As the resistance E. M. F. and inductance E. M. F. differ in phase by $\frac{1}{4}$ of a period, or are 90° apart, they may be represented by straight lines at right angles to each other, the lines by their length representing the values of the E. M. F's. If the triangle is completed by drawing the hypothenuse, this will represent by its length the value of the resultant E. M. F. These values will give the maximum value of these quantities. To show the varying values of these quantities it is only necessary to project their lengths on a straight line suitably placed. Such an arrangement is shown in Fig. 202.

From O is drawn to scale OE_1 in any direction, the maximum value of the inductance E. M. F. and equal to $2\pi nCL$, and from E_1 and at right angles to OE_1 is drawn E_1E_2, the maximum value of the resistance E. M. F. and equal to CR. Then the hypothenuse OE_3 is drawn and it will represent, according to the scale adopted, the maximum value of the resultant E. M. F., and equal to $C\sqrt{R^2 + (2\pi nL)^2}$.

The instantaneous values of the E. M. F's. are found by projecting $E_1E_2E_3$ on the horizontal line ON, where the distances OA, OB, BA measured to scale will be the instantaneous values at any instant when the whole triangle is revolved about O. The instantaneous value of the resultant E. M. F. is the sum of the instantaneous values of the component E. M. F's. Thus the instantaneous value of E_1 is OA, of E_2 is AB (negative) and of E_3 is OB, which is the sum of $OA + (-AB)$. As the triangle is revolved about O, the instantaneous values of the variable quantities may be obtained at any instant. When the line OE_1 is on the line ON, the

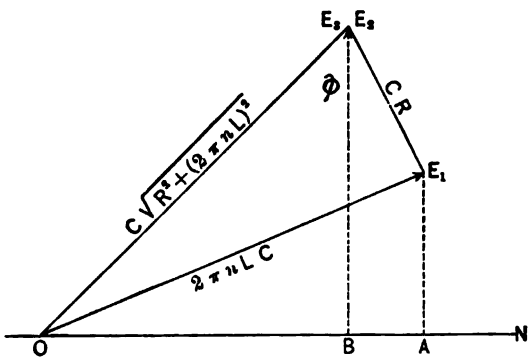


FIG. 202.—Component and Resultant E. M. F's.

projection of E_2 is zero, and E_1 is a maximum as previously seen in Fig. 201.

The angle between the two vectors representing the curves E_2 and E_3 is the phase, represented by ϕ in the figure.

Magnitude of Resultant E. M. F.—In Fig. 202 it is shown how the resultant E. M. F. may be obtained when the component E. M. F's. are known, and as this is the hypothenuse of a right triangle, the value of the resultant E. M. F. can readily be calculated.

$$OE_3^2 = OE_1^2 + E_1E_2^2,$$

or $$V^2 = (2\pi nCL)^2 + C^2R^2,$$

and $$V = C\sqrt{R^2 + (2\pi nL)^2}.$$

Of this value V, CR is spent in overcoming the resistance of the

circuit, and $C2\pi nL$ in overcoming the back E. M. F. of self-induction. If there is no self-induction $L = O$, when $V = CR$, in accordance with Ohm's law.

Impedance.—It has been shown above that the current in an alternating circuit cannot be calculated by Ohm's law, owing to the effects of self-induction, and it acts as though the resistance instead of being R was increased to $\sqrt{R^2 + (2\pi nL)^2}$. The current is not generally governed by the resistance but by the inductance. In Ohm's law, the voltage divided by current gives the resistance, but in alternating currents, the voltage divided by current gives a factor, represented by $\sqrt{R^2 + (2\pi nL)^2}$, which is called the **impedance.**

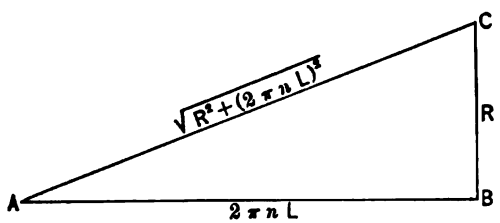


FIG. 203.—Triangle of Resistance and Impedance.

Fig. 202 shows that each side of the triangle of E. M. F's. contains the current factor C, and if each side be divided by C, there will remain a triangle which can be plotted to a scale of resistance. These three sides are represented in Fig. 203.

The side of the triangle BC = resistance $= R$,

AC = impedance $= \sqrt{R^2 + (2n\pi L)^2}$,

AB = reactance $= 2\pi nL$.

If R is small, the impedance becomes practically the reactance and if the inductance is small, the impedance becomes nearly equal to the resistance.

From a consideration of the factors entering into the formula representing the impedance, it is seen that it depends upon the ohmic resistance R, the inductance L, and the speed, or frequency, n. The resistance is independent of frequency, whereas the reactance depends directly on the frequency.

Capacity in an Alternating Circuit.

All conductors possess a certain amount of capacity depending on their form and their nearness to other conductors. This capacity of insulated conductors is so small that it does not prevent the current flowing from obeying Ohm's law; but if the circuit possesses electrostatic capacity given by some form of condenser, a *charging current* will have to flow first into the condenser before the voltage acting on the resistance of the circuit can attain the full value of the applied E. M. F.

In the case of an alternating current, there is a charging current at each reversal of E. M. F., and the total current is the sum of the charging current and the normal current following Ohm's law. As soon as a condenser is charged to full potential, the flow of current will cease until the voltage of the applied current changes. A condenser in a continuous current circuit thus stops all flow of current, but in an alternating current, the potential is continually changing, and the current flows into and out of the condenser, changing its sign.

If Q = quantity of electricity in coulombs
K = capacity of a condenser
and E = difference of potential between terminals of the condenser.

Then $Q = KE$, and a *conductor has unit capacity, one farad, when it is raised to unit voltage, one volt, by one coulomb of electricity.*

The current flowing into a condenser is equal to the rate of change of the charge.

The current is the rate at which quantity of electricity flows, and the charging current will be the rate of change of quantity, or rate of change of KE, and will be equal to the current flowing into the condenser. This charging current, or the current flowing into the condenser, is

$$\frac{Q}{t}, \text{ and since } Q = KE, \frac{Q}{t} = \frac{KE}{t}, \text{ or}$$

the charging current is equal to the capacity times the rate of change of voltage at the terminals.

The relation between charging current and the applied voltage

may be graphically shown as in the case of the current curve and the rate of change due to self-induction shown in Fig. 200.

In Fig. 204, is plotted curve *I* for a maximum E. M. F. of 12 volts, and its rate of change is shown in curve *II*. For convenience in plotting, this curve is plotted for one radian, and the maximum value for one cycle would be $2\pi \times 12$ volts, and for a frequency of n per second, it would be $2\pi n \times 12$ volts.

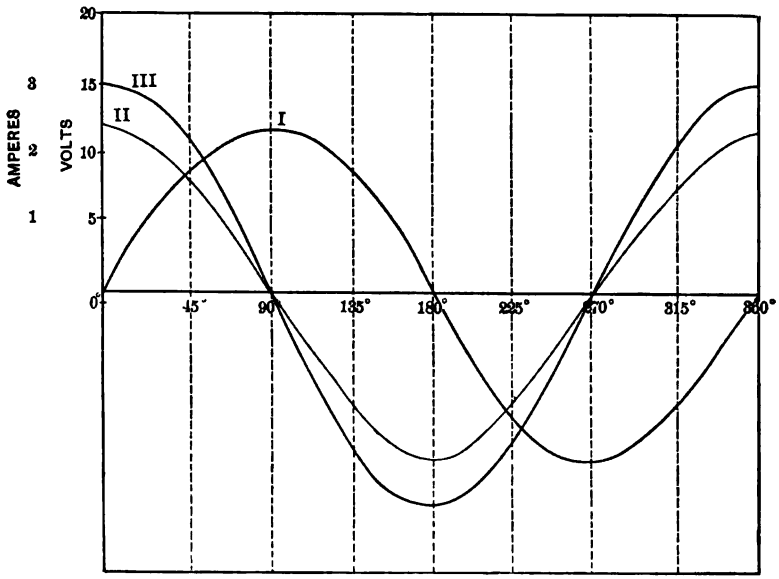


FIG. 204.—Curves of E. M. F. and Charging Current.

If the circuit had a capacity of 400 microfarads and a frequency of 100, the capacity factor would be

$$2\pi nK, \text{ or } \frac{2 \times 3.14 \times 100 \times 400}{1{,}000{,}000} = .25.$$

Since $\frac{Q}{t} = \frac{KE}{t}$, to find the ordinate of the charging current, each ordinate of $\frac{E}{t}$, the rate of change of E. M. F., or curve *II*, must be multiplied by .25. The maximum value is $.25 \times 12 = 3$ amperes, which is plotted as curve *III* on a second scale of amperes.

An inspection of Fig. 204 shows that the charging current differs in phase from the E. M. F. and is always *one-quarter of a period in advance,* and the effect of introducing capacity in an alternating current is to cause the current to **lead,** being just opposite to the effect caused by induction. In addition to this charging current, which is out of phase with the E. M. F., there is the current due to the resistance of the circuit and which is in phase with the E. M. F. This curve of current could be plotted on the same diagram by dividing the ordinates of the voltage curve by the resistance, and the *total* resulting current curve could then be found by adding algebraically the ordinates of the charging and resistance currents, exactly as in the case of finding the resultant curve of E. M. F. in Fig. 201.

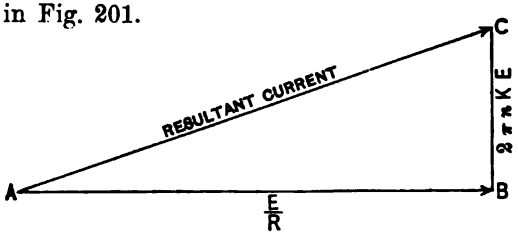


FIG. 205.—Vector Diagram of Currents.

Vector Diagrams.—Similar to the case of resultant E. M. F. the resultant current may be found by vectors, one drawn to scale to represent the resistance current, and another at right angles to represent the charging current, when the hypothenuse will represent the resultant current according to the scale adopted. The resistance current is in phase with the E. M. F. and the angle between this vector and the resultant current vector will be the angle of *lead.* Such a drawing is represented in Fig. 205.

Impedance Due to Capacity.—The impedance, as shown under induction, is equal to the E. M. F. divided by the current, and therefore the resistances of the vectors in Fig. 205 may be obtained by dividing the E. M. F. by the respective currents. Thus, for *AB,* the resistance is

$$E \div \frac{E}{R} = R,$$

and for *BC,* the resistance is

$$E \div 2\pi nKE = \frac{1}{2\pi nK}.$$

A similar diagram may now be drawn for the resistances as in Fig. 206, from which the impedance may be found.

The impedance is $\sqrt{AC^2} = \sqrt{AB^2 + CB^2} = \sqrt{R^2 + \left(\frac{1}{2\pi nK}\right)^2}$.

The current in an alternating circuit depends upon the resistance, and capacity in circuit and the frequency of the alternations.

Impedance Due to Induction and Capacity.—Since induction produces lag and capacity, lead, when these two are connected in series, their effects are opposed and the combined effect of the impedance is given by the formula

$$\sqrt{R^2 + \left(2\pi nL - \frac{1}{2\pi nK}\right)^2}$$

and the expression for the resultant current is

$$C = \frac{E}{\sqrt{R^2 + \left(2\pi nL - \frac{1}{2\pi nK}\right)^2}}.$$

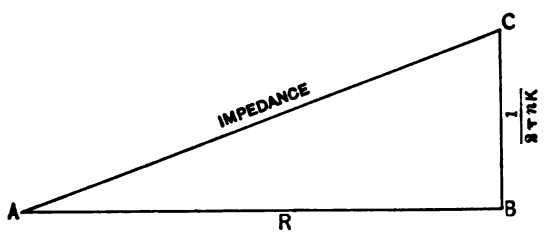


FIG. 206.—Resistance Diagram.

Power.

The power of an alternating circuit, like that of a continuous current, is the product of the E. M. F. and current. This is true for any part of the circuit under consideration, and for any part of an alternating circuit, the power developed is numerically equal to the product of the current flowing in the portion considered and the difference of potential between the two points of the circuit. In the case of alternating currents, as the current and E. M. F. are not in phase, they may be acting in opposite directions, in which case their product must be considered negative.

When the power is negative the circuit is not receiving power from the source of supply, but is giving back power to assist in driving the generator of the currents. As energy is equal to power times time, the energy actually given to any external circuit is equal to the arithmetical sum of the power of the circuit multiplied by the time.

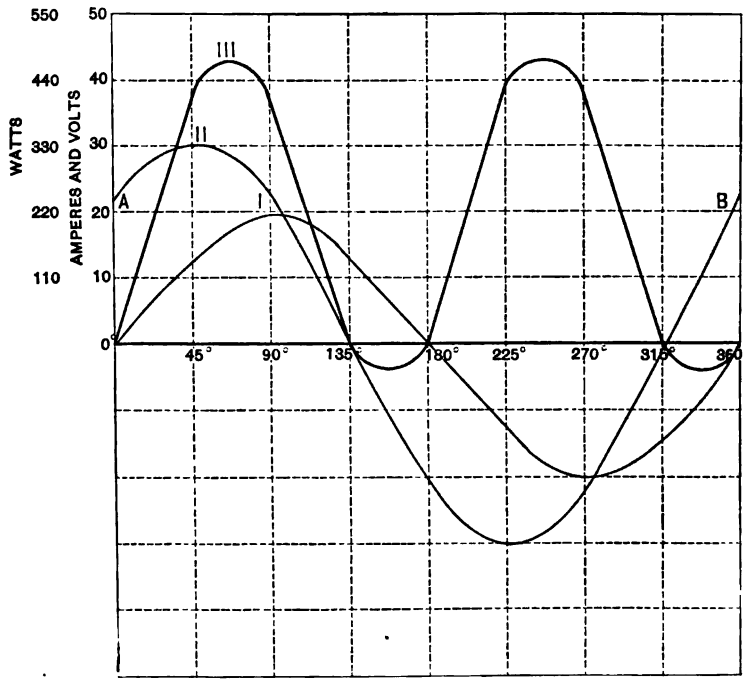


FIG. 207.—E. M. F. Current and Power Curves.

The average power given to an external circuit is the *average* value of the product of volts and amperes. The effect of negative power is shown in Fig. 207 where are plotted curves of E. M. F. and current, from which is plotted a third curve, the watt curve, from values found by the product of volts and amperes for the same instant. Curve *I* represents the resultant current due to a resultant E. M. F. shown in curve *II*, the current leading the

voltage by a phase of 45°. If for any instant, the product of the instantaneous values of E. M. F. and current be found, it will give the power developed in the point of the circuit under consideration. If a number of points be so determined for a cycle, a curve drawn through these points will represent the power or **watt curve**, and curve *III* has been so determined. It must be remembered that all points above the horizontal zero line are to be reckoned as *positive* and those below as *negative*, and the product of two positive quantities or two negative quantities will be positive, while the product of a positive and negative quantity will be *negative*. Thus, all the products will be positive except between 135° and 180°, and between 315° and 360° which will be negative. The curve is roughly plotted to the scale of watts shown on the left-hand side of the diagram.

The **average power** developed in the circuit is the average value of the product of volts times amperes in the circuit. This is found by adding together ordinates of the watt curve and dividing by the number taken. Ordinates below the zero line must be subtracted from those above. The average power is shown in the figure by the dotted line *AB*.

This average power is that indicated by a wattmeter. The readings of a voltmeter and ammeter connected in circuit will not give the true average power by taking their product, for their readings are given independent of the phase of the voltage and current. If these are in phase the product of the volts and amperes as shown by the instruments should be the same as that indicated by a wattmeter, but not otherwise.

If the current and voltage were in phase, there would be no negative power and the average power would be greater, but as the phase difference increases up to 90°, the negative power increases and the positive decreases, and at 90° they would be equal, or the average power given to the circuit would be zero, or the current would be *wattless*. A wattmeter under such condition would indicate zero, while the voltmeter and ammeter would indicate as though the phase was zero, as they would under all conditions of phase.

The product of the voltmeter and ammeter readings gives the *apparent watts*.

The **power factor** is the ratio of the true watts to the apparent watts, or

$$\text{power factor} = \frac{\text{true watts}}{\text{volts} \times \text{amperes}}$$

or true power = volts × amperes × power factor.

The resultant E. M. F. consists of two components, one in phase with the current and one differing in phase by one-quarter of a period. When the resultant E. M. F. differs in phase from the current, by one-quarter of a period, the average power is zero. One component of the E. M. F. therefore does not affect the power of the circuit, and is called the **idle E. M. F.** while the other component multiplied by the current gives the total power, and this component is called the **energy E. M. F.**

The components, energy and idle E. M. F's. are at right angles to each other, the hypothenuse being the total E. M. F., and the phase is the angle between the energy E. M. F. and total E. M. F.

If E is the total E. M. F. the power given out is $C \times$ energy E. M. F. $= C \times E \cos \phi$, where ϕ is the phase.

As the power given out $= C \times E \times$ power factor, it follows that the *power factor is equal to the cosine of the angle of phase.*

Comparison of Values of Direct and Alternating Currents.

In order to compare direct and alternating currents, it is necessary to compare effects which are independent of the direction of the current, and such a comparison is found in their heating effects when passed through resistances.

A direct current of C amperes flowing through a resistance R will develop C^2R joules per second, and an alternating current of equivalent value will also develop the same number of joules per second in the same resistance. Hence the average value of C^2 alternating must equal the average value of C^2 direct. The average value of the square root of C^2 direct is C, but the average value of the square root of C^2 alternating is not the same as the average value of C alternating.

The average value of the ordinates of the sine curve is $\frac{2}{\pi} = .635$,

but the square root of the squares of the ordinates = .707 of the maximum height, or $\frac{1}{\sqrt{2}}$ times the maximum value.

The average value of an alternating current is not used, but rather the alternating current which is *equivalent* to a direct current. This last is called the **virtual** current and is equal to the square root of the average value of the squares, and it is this value which is registered on an ammeter and the one used in designating the strength of an alternating current.

The same remarks apply to an alternating E. M. F. and the virtual volts are those shown on a voltmeter. If a voltmeter showed 70.7 volts, the maximum voltage would be 100 volts and an ammeter that showed 100 amperes would be varying between 0 and 141 amperes.

Most voltmeters and ammeters for measuring alternating currents give readings proportional to the mean values of the square of current or voltage, and if they are designed so that the deflection is proportional to the deflecting force, the division of the scale marks are uneven, as the distance between marks increases in the ratio of the square of the value being measured.

Average Power.—The average value of C^2R in an alternating circuit is one-half the maximum value. The maximum value of the power is equal to the product of maximum volts and maximum amperes, and the average power is $\frac{1}{2}$ (maximum volts times maximum amperes) or $\frac{1}{\sqrt{2}}$ maximum volts times $\frac{1}{\sqrt{2}}$ maximum amperes. These last factors are the virtual values, or

average power = virtual volts times virtual amperes.

It is the *average* value of the watts which gives the true power in a circuit, and this can be found by taking the product of the virtual volts and virtual amperes as shown by the instruments, *if the E. M. F. and current are in phase.* If not in phase, the average value of the power is $\frac{1}{2} CE \cos \phi$, where C and E are virtual values and ϕ the angle of phase.

CHAPTER XX.

DYNAMO ELECTRIC MACHINES.

A dynamo electric machine is defined to be one for converting energy in the form of mechanical power into energy in the form of electric currents or vice versa by magneto-electric induction, the operation being in general that of setting conductors to rotate in a magnetic field.

So far the dynamo electric machines considered have been the generator and the motor, one furnishing and the other absorbing continuous currents. Besides these machines considered as simple units, there are others built from combinations of these two, with combinations of alternating and continuous E. M. F. and currents, each designed to satisfy some definite requirement.

Motor Generators.

These machines are generally designed to change from a continuous current at one voltage to a continuous current at another voltage, and are sometimes called **continuous current transformers.** To do this it is necessary to employ a rotating apparatus which is a combination of a motor and a generator. Two complete machines may be used, each with its own armature and own commutator, fixed to a common shaft, or one single armature may be wound with two separate windings connected to separate commutators. In the first case, there would be two separate magnetic fields and in the second there would be but one.

Current is supplied to one set of windings through its proper commutator at a certain voltage, and the field being excited this machine will act as a motor and will drive the other set of windings as a generator, generating an E. M. F. at its brushes, whose value depends upon the number of windings, the speed and the strength of the field.

If the speed and field are the same, the E. M. F. developed in

each winding is proportional to the number of turns of wire in the winding.

Using the notation of Chapter XII, the relation between the various E. M. F's. and currents are given in the equations:

For motor,

$$\mathfrak{E} = E_1 + C_{1a}r_{1a}. \tag{1}$$

For generator,

$$e = E_2 - C_{2a}r_{2a}. \tag{2}$$

The ratio of E_1 to E_2, the *total* E. M. F's. generated by each winding is constant, or

$$\frac{E_1}{E_2} = k,$$

and so will also the ratio C_1 to C_2 be constant, as

$$E_1C_{1a} = E_2C_{2a} \text{ or } \frac{C_{2a}}{C_{1a}} = k,$$

or from (1)

$$E_1 = \mathfrak{E} - C_{1a}r_a = \mathfrak{E} - \frac{C_{2a}r_{1a}}{k}, \tag{3}$$

and from (2)

$$E_1 = ek + C_{2a}r_ak, \tag{4}$$

and from (3) and (4)

$$e = \frac{\mathfrak{E}}{k} - \left(\frac{r_{1a}}{k^2} + r_{2a}\right)C_{2a}.$$

This gives an expression by which e, the difference of potential at the generator brushes can be found from $\mathfrak{E}$, the difference of potential at the motor brushes.

The amount of power developed by the generator depends on the efficiency of the system, which is the ratio of the input of the motor to the output of the generator, or using the previous notation

$$\text{Efficiency} = \frac{\mathfrak{E}C_1}{eC_2}$$

where C_1 represents the current absorbed by the motor and C_2 the current delivered by the generator. Thus a system with an efficiency of 80 per cent, absorbing 50 amperes at 125 volts would deliver the 50 amperes at 100 volts, thus

$$\frac{125 \times 50 \times 80}{100 \times 100} = 50,$$

or if the windings in the generator were only half as many it would deliver 100 amperes at 50 volts.

Motor generators are used on ships of the navy in connection with the turret-turning and gun-elevating systems, the generators producing variable voltages, effected by varying the field excitation of the generator ends.

The specifications for motor-generator sets for gun-elevating equipments as issued by the Navy Department are as follows:

Specifications for Motor-Generating Sets for Gun-Elevating Equipments.

1. To consist of a direct-current 120-volt motor and a direct-current 130-volt generator of such capacity as may be directed, with common annealed cast-steel frame having suitable supporting feet; both armatures to be mounted on a common shaft, with commutators toward the shaft ends; unless otherwise specified, rotation to be right hand—*i. e.*, clockwise, facing motor end; bearings to be supported by end shields; these shields to be secured by bronze bolts, and so designed that weight of armature is taken by a flange forming a finished working fit in end of frame. Sets to be convertible to wall or ceiling suspension merely by rotating the end shields.

2. Sets to be of the totally enclosed and water-tight type, with suitable hand-holes for inspection and adjustment of brush rigging and for inspection of commutators; all holes to be fitted with water-tight covers, setting up on either ⅛-inch cloth insertion gaskets of navy standard quality (Spec. 23P4) or on strip gum gaskets; these covers to be satisfactorily secured by tobin bronze bolts with hinged composition handles to permit their ready removal and replacement without the use of tools; each cover to have at least two securing bolts and a handle for lifting. Drain cocks shall be fitted to the frame to permit drawing off water which may collect on the interior.

A slotted brass ½-inch pipe plug to be fitted from exterior to each end shield in proper position to permit by its removal inspection of oil rings and filling of wells; plug to be secured by swivel and about six inches of plumber's brass chain No. 2.

3. Frame to enclose two separate magnetic circuits, each having four or more equally energized poles.

4. Shaft to be of steel, with accurately fitted journals; to run in two bronze self-oiling bearings, one at each end of the frame; to be provided with suitable means to prevent oil from bearings working along to armatures; bearings to be provided with sight glasses on oil chambers and suitable drains for removal of oil at will.

5. Frame to be divided horizontally, the two parts to be bolted together, to permit ready removal of armatures and field coils.

6. There shall be but two studs for the generator brush rigging and but two studs for the motor brush rigging, all to be accessible from the

top; the design of brush mechanism to be such that when end shields are rotated for wall or ceiling suspension the brushes will be maintained in proper position relative to hand-holes.

7. Generator field to be shunt wound to adapt the machine for furnishing power for the Ward-Leonard system of control. The saturation curve must show practically a straight line up to 110 volts (armature terminals) and must not show saturation at 140 volts.

8. Sets to be designed for speed not exceeding 2000 revolutions per minute—the design to be with a view to minimizing weight and overall dimensions; speed variation between no load and full load and from full load to no load not to exceed 10 per cent of normal.

9. Commutator bars or segments to be supplied on a shell which must be directly attached to the spider or keyed to the shaft; bars to be *hard drawn copper*, finished accurately to gauge; insulation between bars to be of carefully selected mica, gauged to uniform thickness and of such hardness as will wear evenly with the commutator bars.

10. Bars to line with the shaft and run true; to be securely clamped by means of bolts and clamping rings; clamping adjustments to be accessible in finished armature. There shall be no openings by which any foreign substance can get to the interior of the commutators. The commutators and brush rigging must be designed to permit handling heavy and fluctuating loads up to as high as 200 per cent overload.

11. Brushes to be of carbon; current density at normal full load not to exceed 35 amperes per square inch; each stud to carry two brushes; each brush on a stud to be capable of separate removal or adjustment, and means shall be provided for simultaneously shifting all brushes; brush holders to be of the sliding shunt-socket type; springs to be of material other than steel and must not be relied upon to carry the current; brush stud insulation to be absolutely moisture proof.

12. Finished armatures to run true and be balanced both electrically and mechanically. The completed sets must run at all loads without noise or vibration.

13. A name plate to be fitted to each motor generator in a conspicuous place, containing the following data:

MADE FOR
BUREAU OF EQUIPMENT
BY
(*Name of maker here.*)
Req. No. —. Date —. Rating —.
Factory No. —. Volts. —. Amp. —.
Field (Gen.) —. Amp. —. Ohms —.

Factory number to be also stamped on the frame under the name plate.

14. Separate name plates shall be fitted to indicate which is the motor and which is the generator end.

15. The entire construction of the sets must be free from iron castings as far as possible.

16. The overall dimensions must not exceed the following: 8 kilowatts, 21 by 21 by 40 inches long; 5½ kilowatts, 19 by 19 by 32 inches long; 3½ kilowatts, 17 by 17 by 28 inches long.

17. The design must be such that when installed in confined spaces, with but 4 inches clearance at each end, the end-shield bolts can be removed, the upper parts of the field frames can be lifted, and the armatures removed or replaced.

18. There shall be no wires carried to the exterior of the frames, but the internal arrangement shall be such that the connecting wires can be suitably carried to their proper contacts with the machine assembled. These wires will be carried in conduit pipes which will tap directly into the lower part of the frames, but the frames need not be tapped by the builder unless specifically required. Two armature leads and one field lead will pass to the motor end; two armature leads and two field leads will be taken from the generator end.

Rotary Compensators.

These are machines built very much like motor generators and are used to change the voltage of one continuous current to other voltages of continuous current. Their particular action is more fully described under descriptions of various turret-turning systems. They consist in general of two complete machines with separate armature windings, commutators and brushes, and with separate magnetic fields. The armatures are mounted on a common shaft. In their first operation they are motors, but deliver currents to other motors at varying voltages by changing the excitation of their fields.

Extracts from specifications issued by the Navy Department follow:

"The compensator to be entirely enclosed and water-tight, but provided with openings of sufficient size and number to give easy access to the commutator, brush rigging and field coils, such openings to be provided with water-tight covers and clamping devices of approved construction.

"The field frame will be of steel and enclose two separate magnetic circuits; it will be separable in a horizontal plane through

the axis to permit of ready removal of armature and field coils. The two armatures will be carried on one shaft of ample strength, and forced ventilation or fans on the armature shaft will not be permitted. The compensator to be capable of wall or ceiling suspension.

"Fields will be so compounded as to best adapt the machine to the purpose for which it is intended. The series winding is to compensate for the resistance drop in the armature and leads to the motors, and shall be such as to give as nearly a straight line compounding curve as possible.

"The set to be designed for operation at 120 volts across the line. The maximum speed of the compensator must not exceed 1500 R. P. M."

A description of a rotary compensator as actually installed is given by the makers, the General Electric Company.

Rotary Compensator.

The rotary compensators are totally enclosed and consist of a common cast-steel magnet frame, containing two field magnetic circuits and enclosing two armatures mounted upon one shaft supported in bearing heads at the outside ends.

Magnet Frame.—The magnet frame consists of a cast-steel shell octagonal in shape and separable in a horizontal plane through the armature shaft. Steel bolts hold the halves of the frame together and feet are cast with the lower half for fastening the motor-generator set to its support.

Openings are made at the top, sides and ends of the frame to give access to the brushes. The covers for these openings are all solid sheet metal made water-tight by rubber gaskets. The covers over the commutator and at the frame ends will be secured by wing bolts, thus making them easily removable for inspection and adjustment of the brushes.

Pole Pieces.—Four laminated steel pole pieces in each frame support and retain the field coils and are held in position by bolts passing through the magnet frame.

Armature Bearings and Linings.—The armature bearings of the self-oiling and self-aligning type, are cast with the end shields

which fit accurately bored seats in the ends of the magnet frame. Oil rings supply ample lubrication, and a combination sight and overflow gauge is provided with each bearing of such a height that oil will not overflow inside the magnet frame. Holes in the top of the bearings, furnished with suitable covers, provide means for filling the oil wells and inspecting the oil rings and provision is made for drawing the oil from the reservoirs.

The split linings are of bronze and held from turning by dowel pins.

Field Coils.—The field coils fit around and are held in place by the pole pieces. They are insulated with pressboard and varnished cambric and then treated with several coats of insulating baking japan, making them thoroughly water-proof. The ends of the windings are soldered to connectors. The fields of both machines are compound wound, the shunt being over the series.

Armatures.—The armatures are of the multiple drum type having laminated steel cores, with air ducts for ventilation, supported on cast-steel spiders separately keyed to the shaft with commutators at the ends. The cores are slotted to receive the armature coils, the slots being punched in the laminations before being assembled. The coils are form wound, thoroughly insulated with oiled muslin, tape and japan, and securely held in the slots of the armature core by binding wires.

Commutators.—The commutators consist of hard drawn copper segments carefully insulated with mica and supported on cast-steel shells which are securely keyed to the shaft. The ends of the armature coils are soldered into the commutator segments.

Brush Rigging.—The brushes of carbon and of ample cross-section are carried in brush holders supported on four insulated brass studs bolted to an adjustable yoke. The brush holders are supplied with adjustable springs for regulating the brush tension and alternate studs are connected by bus rings.

Series Field Shunt.—The adjustable shunt on the series field consists of a slate having two terminals about 10 inches apart, upon which German silver strips can be bolted, the adjustment to suit ship conditions, being obtained by changing the number or section of these strips.

Cables and Connections.—The frame is to be supplied undrilled so that it can be tapped for conduit by purchaser for armature and field leads to suit ship conditions.

External Field.—There will be no appreciable field at a distance of 15 feet from the machine in any direction.

Non-Corrosive Parts.—All small screws, nuts, etc., which are liable to become corroded and thus broken in removal are to be made of non-corrosive metal and not of iron or steel. Flat springs are to be of phosphor bronze, and spiral springs of steel, copper-plated.

Tests.—The compensator will be subjected to the following tests:

(1) With the two shunt fields connected in parallel across the line, the armatures being in series, the set is to be run without load for a continuous period of three hours. At the end of this time the temperature rise of the shunt fields must not exceed 50° C. measured by resistance.

(2) The set to be immediately started and run under conditions of full current and maximum voltage in the large motor (corresponding to minimum current in the field of armature for operating small motor) for a continuous period of one hour.

(3) Within one-half hour after completion of test (2) the set is to be run for a period of one hour under conditions of minimum compensator voltage and full current to large motor.

The temperature rise under the above conditions shall not exceed the following:

Series field	70° C.	by thermometer.
Shunt field	50° C.	by resistance.
Commutator	65° C.	by thermometer.
Armature	60° C.	by "
Bearings	35° C.	by "
Other parts	60° C.	by "

In addition, the compensator is to be subjected to an overload of 50 per cent for five minutes under the conditions specified in (2) and (3) above.

All windings are to withstand 1500 volts alternating for one minute.

Weight.—The approximate weight of the set is 3000 pounds.

Dynamotors.

These are machines for supplying continuous currents at various voltages. They differ from motor generators in the fact that they have but one field for both the motor and generator while the motor generator has a separate field for each. This makes a much better balanced arrangement than the two fields of the motor generator, as all armature reactions are neutralized; there is no tendency to spark at the brushes and the brushes do not have to be shifted for changes of load, as all reactions due to generator characteristics are balanced by those of the motor which act in a contrary sense. Any change in the field affects both motor and generator, and will simply make them run faster or slower.

The armature coils are wound on the same core, and in general the coils of the motor are wound first and imbedded in slots. Those for the generator wound over them are connected to a commutator at the opposite end from the motor connections.

Dynamotors are used on shipboard for reducing the voltage of the main generators to lower values for use with the different systems of interior communication.

They are ½ horsepower and take about 3 amperes at 125 volts, transforming to 20 volts for general alarm bells and by adding auxiliary brushes, 13.3 and 6.6 volts may be obtained for call bell or other work.

Rotary Converters.

These machines are constructed for changing a continuous current into an alternating current, or vice versa. Like motor generators, they may be built with separate armatures and commutators with separate fields or with but one armature with one winding and one field, fitted with two commutators, one for continuous current and one for the alternating current.

In those built as two separate machines with the armatures secured to one shaft, the action is simply that one may be used as a continuous-current motor to deliver alternating currents at the other commutator, or alternating currents may be supplied to drive one, delivering continuous current at the other commutator.

The case of one armature with one winding with connections to a

commutator and collector rings, one connection for continuous current and for alternating currents, requires some explanation.

Let Fig. 208 represent a single ring armature revolving between a pair of magnetic poles, two opposite points being connected with collecting rings, *C* and *C*, upon which brushes make contact to take off the current.

When the armature is in the position shown, all the wires on each half are sending current in the same direction, and let the winding and field be such that it is up in both halves, making the outer ring *C* positive and the inner one negative.

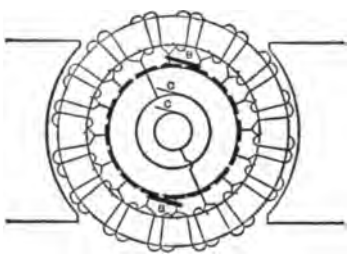


FIG. 208.—Diagram of Rotary Converter.

Now suppose the armature has turned a quarter turn, then, as before, all the wires on each side are trying to send current towards the top, but the connections to the rings have turned with the armature and there is no connection at the top to take it off. The E. M. F's. generated on the two sides of each half are opposed and exactly equal, so there is no net E. M. F. between the collecting rings and there is no current at that instant. Between the positions when the connections are vertical and horizontal the E. M. F. and current vary more or less uniformly.

Now suppose the armature is provided with a commutator, each section of the armature connected to a commutator bar, and with brushes *B* and *B*, which make contact with the commutator segments. These brushes make contact with different segments of the commutator as the armature revolves, while *C* and *C* always make contact with but one section of the armature winding.

It is seen then that the armature wires between *B* and *B* all

tend to send current in the same direction at all positions of the armature, so that a continuous current may be taken from *B* and *B*, while at the same time an alternating current may be taken from the same armature by *C* and *C*.

Since either a continuous or an alternating current may be obtained from the same armature, it makes no difference what causes the armature to rotate, and therefore if continuous current be applied to the brushes *B* and *B* alternating current may be taken from the brushes *C* and *C;* and similarly, if alternating current be supplied to the brushes *C* and *C* the machine will run as an alternating current motor and continuous current taken from *B* and *B*.

Relation of Voltages between the Continuous Current and Alternating Current Brushes.—From Fig. 208 it is seen that the alternating voltage is at a maximum when the armature coils connected with the collecting rings are also connected with the continuous current brushes, and therefore the maximum value of the alternating voltage is equal to the steady value of the continuous voltage. The **mean** value of the alternating voltage is only 70.7 per cent of the maximum, while the actual values vary from zero to the maximum.

Different Phase Currents.—A rotary converter with only two collecting rings as shown, would give a single-phase current. Two-phase currents could be obtained by having a second pair of collecting rings connected to the armature windings at points midway between the first ones. The E. M. F. between one pair would be a maximum when that between the other pair was at zero. The currents would then be at right angles and the effective values of the E. M. F's. would be equal. By connecting three collecting rings to three equidistant points a **three-phase** current could be obtained from a rotary.

In the three-phase current, the effective voltage between any two of the collecting brushes is 62 per cent of the continuous voltage.

Rotary Connectors for Wireless Sets.

These machines are of the two-field, two-armature type, with one end fitted with a commutator for continuous currents and the other

with collector rings for alternating current. The armature is driven as a motor by continuous current from the ship's power mains, driving the other as alternator.

The object to be gained is simply the conversion of continuous current into alternating current for use in the primary of induction coils used in wireless sending apparatus, without much change in potential. It is usual to insert variable resistances in the field of each armature so as to vary the voltages of each within small limits.

Size of Converters.—Converters are rated according to their output capacity expressed in kilowatts. Thus a 5-kilowatt converter is one whose product of E. M. F. at the terminals and output current is equal to 5000 watts or 5 kilowatts. Thus one form used has an input of 125 volts with 52.5 amperes and an output of 110 volts and 45.5 amperes, or practically 5 kilowatts.

CHAPTER XXI.

TESTS AND EXPERIMENTS WITH DYNAMO ELECTRIC MACHINES.

The general idea of making tests of a completed machine is to discover whether it complies with the specifications under which it was constructed and is able to supply a certain amount of power. At the same time, it is by actually experimenting with electrical machines that a sound knowledge of their underlying principles may be most readily gained.

General Tests.

As a matter of procedure in making tests of dynamo electric machines the following list gives a general indication of the points to be considered:

1. The general study of the machine.
2. Mechanical strength of parts against breaking.
3. Balance of armature.
4. Sparking at the brushes.
5. Noise.
6. Resistances of the various windings; armature, field, etc.
7. Characteristic curves for internal, external and total circuits.
8. Variation of speed under different loads and temperatures.
9. Dielectric strength and insulation resistance.
10. Heating.
11. Efficiency.
12. Determination of losses.
13. Determination of E. M. F. around armature.

Study of a Dynamo.

Under this head the following general points should be particularly considered:

1. Tabulation of electrical and mechanical points of design.
2. Adjustment and fit of parts.
3. Lubrication.
4. Workmanship and material.

A careful inspection of the machine should be made while at rest, noting every point connected with the field, armature, commutator, brushes, brush rigging, headboard, etc., so that facts ascertained can be compared with the specifications, or if none are furnished, the points developed will help to make a complete description of the machine.

The general form of the field frame should be noted with the number of field spools and poles, also the method used to connect the terminals of the windings from one field spool to another. The number of the terminals on each spool will indicate the form of field winding; whether series, shunt or compound. If a compound machine it will be seen whether the two windings are separate or one on the other, noting which is on the outside. An inspection will show whether the pole pieces and magnet core are in one with the field frame or whether they are separate and bolted together.

The construction of the armature would show its type of winding, whether ring or drum, and the fact should be noted whether the conductors are wound directly on the armature core or are imbedded in slots. The commutator segments should be counted and the method of securing the armature windings to them noted; that is, whether they are clamped, screwed or soldered.

The kind and number of brushes should be noted and the mechanical design of the brush holders and the means employed to move all the brushes together should be examined. The brushes should be removed and replaced to become familiar with the various springs and attachments and the brushes should be rocked back and forth by the rocker arm and clamped in different positions.

The headboard should be inspected and the different terminals marked, so that the series and shunt terminals and armature and equalizer leads can be readily distinguished. This will also show whether the machine is a long shunt or short shunt in case it proves to be a compound machine.

The maker's name-plate furnishes important information, such as the power expressed in kilowatts, the revolutions of the armature per minute to produce the required E. M. F., the E. M. F. at the terminals, the current output, type of field winding, etc. This information should be tabulated to be verified by tests and experiments.

Adjustment and Fit of Parts.—The adjustment and fit of all parts should be carefully examined and particular attention should be given to the brush rigging. Brush holders ought to be readily accessible for adjustment and renewal of brushes and springs, and adjustable for tension, generally without tools, and constructed to admit of proper staggering of brushes.

Lubrication.—All bearings should be provided with oil wells of sufficient capacity and inspection should be made to see if any arrangement is provided to prevent oil running along the armature shaft. The best practice requires self-oiling bearings provided with split babbitted bearing linings, and visual oil gauges for determining the amount of oil in pockets and drains for drawing off oil.

Workmanship and Material.—Naturally the materials and workmanship of all parts of any machine should be of the best quality, and notes should be made of any particular part that shows evidence of inferior workmanship or defective or cheap material, and all windings should be carefully observed for any signs of abrasion of the insulation or outside covering. Special attention should be given to the workmanship and material of the brush rigging and springs. The best practice requires all metal portions to be non-corrosive and fitted with flexible connections between brush and holder. Brushes should be carefully examined and their quality should be such as to give perfect contact without cutting, scratching or smearing the commutator.

Mechanical Strength.

All the main parts of dynamo electric machines as the base, field frames, field magnets, armature, shaft, bearings, etc., should be of such strength that they will not spring with any reasonable force. The strength to resist centrifugal forces due to the armature revo-

lution should be tested by running the armatures to at least double their normal speed without load, and series motors should be run at four times their full-load speed. There should be no signs of weakening of any part of the armature when run at these increased speeds for at least thirty minutes.

Balance of Armature.

Before commencing any test requiring the movement of the armature, carefully turn it by hand or jack over the engine if directly connected to its shaft, looking at the same time for any obstruction to free movement. When satisfied that all is clear make ready for slowly turning over the armature with the motive power supplied.

In case of a steam engine, either directly driven or by means of a belt, see the oil service in working order, and take all the usual precautions in starting the engine; exhaust open, water clear of cylinders, drains and relief valves open, bearings oiled and that the cylinders have been properly warmed. In turning over the armature for the first time make sure that the external circuit is opened and that the brushes are raised clear of the commutator.

Open the throttle and let the engine turn slowly and watch the revolution of the armature, noting whether it revolves concentrically; that it does not strike the pole pieces at any point; that there is equal clearance between armature and the pole pieces all around and that it runs smoothly and free from undue vibration. The alignment of the shaft should be noticed and one not true would soon manifest itself by heated bearings and these must be watched from the time the engine is started.

The perfection of balance of armatures of generators should be tested by running them at least 25 per cent above their normal speed; of shunt motors at their normal speeds; of series motors from normal to double their rated speeds, and of compound motors from normal speed to 50 per cent above normal. In all cases the armatures of well-designed machines should not show the slightest vibration.

Sparking at the Brushes.

The causes of brush sparking are given in Chapter XXXI and if any sparking occurs during a test, its cause should be sought and the machine credited with a defect. Modern well-designed generators and motors should show no signs of sparking whatsoever under any changes of load within their capacity and generators under ordinary conditions should show no sparking when overloaded 25 per cent, nor should any change in the brushes be a necessity to prevent it.

Motors to run in the open should show no signs of sparking from no load to full load and enclosed motors from no load to 25 per cent overload and without shifting the brushes. No sparking should also hold under all conditions of weak or strong field.

Noise.

All armatures of generators and motors should run at their full rated speed and load practically without noise or humming sounds and without rattling or chattering of the brushes.

Resistance of Windings.

The ohmic resistances of all parts of the armature windings, series and shunt windings should be carefully measured and recorded so that the values of the fall of potential through the various circuits can be checked and the calculated value of the external energy compared with that actually obtained.

A method for measuring these resistances is given in the chapter on Measurements. All the different methods used for measuring such small resistances as that of a large armature or the series winding are based on the "fall of potential" method and require the use of some standard small resistance, and the accuracy of the measurement depends on that of the standard resistance. The method described in the chapter referred to is available for use on board ship with the instruments usually furnished, but if a laboratory is available other methods can be used with possibly more accuracy; and such is one given below.

Measurement of Armature Resistance by Comparison of Deflections.—This depends on the following general principle: *If two resistances have the same current flowing in them, the differences of potential at their ends is proportional to their resistances.*

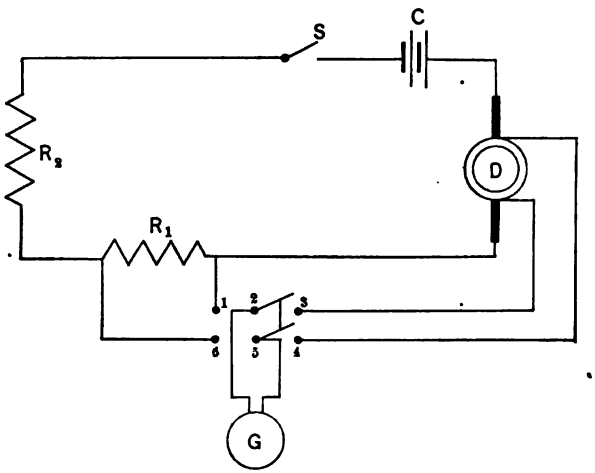


FIG. 209.—Measurement of Armature Resistance.

In Fig. 209

D is the armature and resistance,
R_1 standard resistance, approximately equal to that of D,
R_2 variable resistance,
C one or two cells (preferably secondary cells),
G galvanometer,
S switch,
1, 2, 3, 4, 5, 6 terminals of a double-pole, two-throw switch.

The leads of the circuit containing the cells are connected to the brushes, disconnecting the field windings. The wires from the armature to the galvanometer are connected between the brushes and the commutator, making sure that the wires press on opposite segments and make contact with one segment only.

The galvanometer should have a uniformly divided scale and its reading should be proportional to the deflecting current. If it is a

very sensitive one, it may be necessary to use a shunt, or a resistance in series with it will often give the desired result.

The resistances of the leading wires to the galvanometer does not affect the accuracy of the measurement as they are so very small compared with that of the galvanometer, and the latter may be far removed from the machine where it will be free from any influences other than the deflecting current.

Instructions for Test.—Close the switch S and by means of the switch hinged at 2 and 5 connect the galvanometer to 1 and 6, so that it is connected to the circuit containing the standard resistance. Adjust resistance R_2 to get a good readable deflection. Note the deflection on the scale of the galvanometer. Reverse the switch to 3 and 4, connecting to armature and note the deflection. Reverse the switch and repeat the first reading, and repeat the whole operation five or six times.

Let d_1 be the mean of all the deflections when connected to R_1,
d_2 be the mean of all the deflections when connected to D,
V_1 the fall of potential through R_1,
V_2 the fall of potential through D.

Then

$$\frac{d_1}{d_2} = \frac{V_1}{V_2},$$

and by the principle stated above

$$\frac{V_1}{V_2} = \frac{R_1}{D},$$

or

$$\frac{R_1}{D} = \frac{d_1}{d_2} \text{ and } D = \frac{R_1 d_2}{d_1}.$$

Connecting the leading wires from the galvanometer to the brushes will give the resistance of armature, brushes and contacts, and subtracting this value from the armature resistance will give the resistance of brushes, brush holders and contacts; an item sometimes of great importance.

This method is suitable for measuring resistances between .1 and .001 ohm, but for resistance lower than these values, other methods must be resorted to, such as that by the Thompson bridge, which will measure as low as .0001 ohm.

Measurement of the Resistance of Field Windings—Series Winding.—As this is of very low resistance, either the method given in the chapter on Measurements or the method given above may be used, inserting the series winding directly in series with the cell circuit.

Shunt Winding.—Either of the two methods given in the chapter referred to may be used, viz., by the Testing Set or Bridge, or by the Voltmeter and Ammeter method.

In measuring the resistance of the shunt winding, it is usual to measure both the *cold* and *hot* resistance. The voltage applied to the shunt terminals should be the normal working voltage and readings of the voltmeter and ammeter should be taken at regular intervals of time.

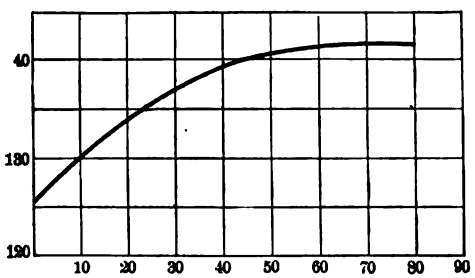


FIG. 210.—Curve of Resistance.

Curves plotted with intervals of time as abscissæ and the resistances obtained at the corresponding time as ordinates are instructive. Fig. 210 shows a curve obtained in this manner.

The numbers on the bottom line represent seconds of time and those on the left, resistance in ohms. This shows that the resistance at first increased rapidly with the time, then more slowly and became approximately constant after an hour's time of running, and the greatest value would be the *hot* resistance.

Characteristic Curves.

Characteristic curves of electrical machines have been referred to in the chapter on Generators, but it is the purpose here to go more into the details of the methods used in obtaining these curves and

to show graphically the necessary connections for making this part of the electrical tests.

The following curves are the most important ones for which data are taken for tests or experiments on generators of the classes named: **Series generator:** *external circuit; total circuit; magnetization.* **Shunt generator:** *external circuit; internal circuit; total circuit; armature.* **Compound generator:** *compound; differential series, external circuit; internal circuit.*

Characteristics of a Series Generator.—The curve usually obtained by observation is the external circuit curve as this can be found by connecting up a voltmeter to show the fall of potential in the external circuit, and by including an ammeter in the circuit. The connections are shown in Fig. 211.

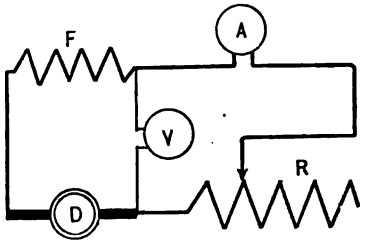


FIG. 211.—**Connections for External Circuit Characteristic of Series Generator.**

The voltmeter V is connected to the terminals of the machine (note, not to the brushes) and the ammeter A is included in the main circuit in which there is a variable resistance R.

Instructions.—Add resistance in R until both the E. M. F. and current are quite small, and take simultaneous readings of both instruments and record them. Then vary (decrease) R by successive amounts so that successive points on the curve can be obtained, it being generally advisable to make the reading an even number of amperes for convenience in plotting. This operation can be carried on up to the safe carrying capacity of the machine.

For any given value of current a small change of speed produces an approximately proportional change of E. M. F., so if the speed varies, which should be tested at each reading by a tachometer, the

voltmeter readings should be corrected to some convenient constant speed near the mean.

With the data obtained plot the amperes as abscissæ and the differences of potential as ordinates, according to some convenient scale, and draw a fair curve through the points obtained.

Then with the resistances of the armature and field, calculate the volts lost in the armature and field for each value of C, by the equation $C(r_a + r_m)$, see Chaper XII, and plot the internal resistance line. Then add these values vertically to each of the points on the curve corresponding to the values of C, which will give a series of points, through which the **total circuit curve** can be drawn. These curves are shown in Fig. 75.

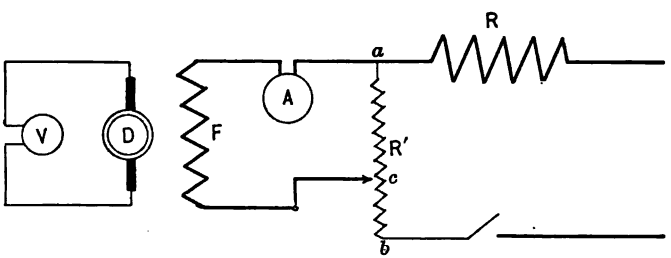


FIG. 212.—Connections for Obtaining Magnetization Curve.

Magnetization Curve.—This curve shows the relation between the exciting field current and the resulting E. M. F. produced by the armature at no load.

The diagram of connections is shown in Fig. 212.

The series field F is disconnected and the voltmeter V is connected to the brushes of the armature D. The field winding is connected to an outside source of E. M. F. of value equal to that produced by D. The change of exciting current may be effected in either of two ways and both are given for purposes of instruction. R, a variable resistance may be changed, thereby effecting change of current in F, or the difference of potential at the terminals of F may be varied by the resistance R'. This is a resistance of sufficient carrying capacity not to become overheated when permanently connected to the source of supply and also carrying the field current. The field winding is connected to one end of this

resistance, a, and to a movable point c, which slides along ab. As c is moved towards a, the difference of potential between a and c decreases, consequently decreasing the current through F.

Instructions.—Begin with the exciting current zero or very small, by varying either R or R' or both. Note the simultaneous readings of A and V. Vary the exciting current as desired and note the readings, and continue this until the maximum current in F is reached. Then decrease the current by similar steps. For each value of A read V, and note the speed of D. Reduce the readings of V to some constant speed from the formula

$$V = \frac{V'n}{n'}$$

where V' and n' are the E. M. F. and observed speed and V the desired E. M. F. and n the normal speed.

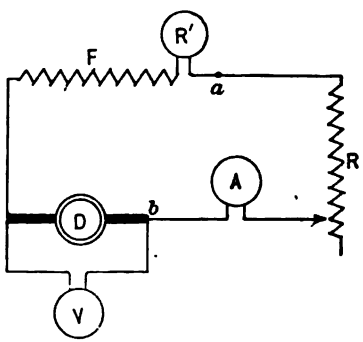


FIG. 213.—Connections for Obtaining Shunt Internal Characteristic.

With the observed values, plot curves as before, with current as abscissæ and E. M. F. as ordinates for both ascending and descending values of exciting current. It will be found that this gives two distinct curves, and the failure of the two curves to coincide is due to the *hysteresis* of the magnetic circuit, and the distance apart of the curves will be an indication of the nature of the metal used in the circuit as regards hysteresis. Soft iron shows little hysteresis while hard iron or steel shows the effect very strongly.

The form of the magnetization curve resembles very closely that of the total circuit curve of the series machine, which should be natural, as the E. M. F. is directly proportional to the magnetization and that in turn to the amperes of the exciting current.

Characteristics of a Shunt Generator—Internal Characteristics.—The curve of the internal circuit is obtained by disconnecting the external circuit; that is by leaving it open, when the machine

practically becomes a series machine with the external circuit short-circuited, so the resulting curve should show the general form of the series total or magnetization curves.

The connections to be made for obtaining the necessary data are shown in Fig. 213.

The terminal *a* of the shunt field *F* with its regulator is disconnected from *b* and between these points is inserted the variable resistance *R* with ammeter *A* in circuit. This resistance is added to allow a greater change of voltage and resulting current so as to obtain more points on the curve.

Instructions.—It is well to start this experiment with very little magnetization, or with all resistance in the regulator and *R*. When the armature is running at its normal speed, and all resistance in, take readings of *A* and *V*. Then vary the resistances till the ammeter shows an even number of amperes as 5 or 10, and read *V*, checking the speed at the same time. Then make *A* read 10, then note *V* and so on up to the safe carrying capacity of *F* or to the point of saturation of the magnets. Correct all speeds to that of the mean speed as previously explained.

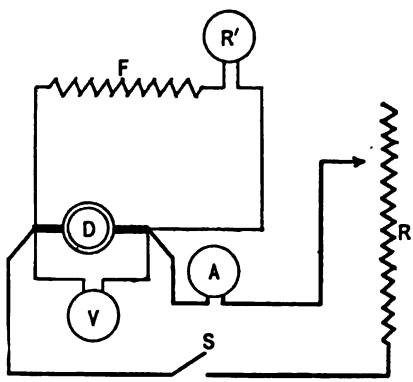


FIG. 214.—Connections for Obtaining Shunt External Characteristic.

With the data obtained, the curve can be plotted in the usual way with amperes as abscissæ and volts as ordinates. If the experiment was commenced with low resistance or high magnetization and the current stepped down, the resulting curve would be slightly different from the first and as the curves are all for the purpose of comparison, it is better to take them starting from the same point; that is, with either increasing or decreasing magnetization.

External Shunt Characteristic.—The connections for obtaining the necessary data for this curve are shown in Fig. 214.

There are no changes in the connections of the machine itself,

but the variable resistance R is introduced in the external circuit with the ammeter in circuit.

Instructions.—At first leave the outside circuit open and adjust the regulator in the field so that the generator at normal speed will give the normal E. M. F. This gives the first point on the curve, zero current and maximum E. M. F. Do not change the regulator resistance during this experiment.

Close the external circuit through switch S with enough resistance in R to give a small resulting current in external circuit. This is a matter of simple calculation, knowing the E. M. F. and the current desired, the amount of resistance is readily known.

Read both A and V and note speed. Vary R for a new value of A and note the simultaneous readings and take the revolutions to be corrected as in other cases already described.

It is more than probable that starting as above, the safe-carrying current will be reached before the curve can be completed; that is, before the E. M. F. falls sufficiently to cause its resulting current to drop. In this case start with a lower E. M. F. on open circuit by changing the regulator and then the complete curve may be obtained.

The general form of these curves is shown in curve 1 (Fig. 78) and also the method of obtaining the other curves from this one.

Precautions.—To obtain good results, care should be taken not to break the circuit or to make too large changes in the variable resistance.

If at any time a new point is further from the last one taken than desired, it is better not to go back, for the curves for increasing and decreasing magnetization are different.

If the external circuit should be broken while working on the lower part of the curve, the magnetization would run up at once and if the circuit was now closed through the same resistance, there would be danger of getting an excessive current before the magnetization would fall to its previous state. In this case it would be better to throw all resistance in before closing the switch and then gradually reduce it till the conditions are the same as before the break.

When the resistance is nearly all out so that the E. M. F. has

fallen, bringing the lower end of the curve near the current line, the curve for increasing magnetization may then be started without any break of circuit or change of any kind, and if care is exercised and the change of resistance is very small and gradual, the two curves can be completed, forming a loop at the lower end.

If the up curve is to be started first, the field circuit should be left open before closing the external circuit, or short-circuiting the brushes (all the external resistance being out). After the external circuit is closed the field circuit can be closed, for then the E. M. F. at the brushes and current in the field is almost zero. The value of current for zero potential at the brushes depends upon the

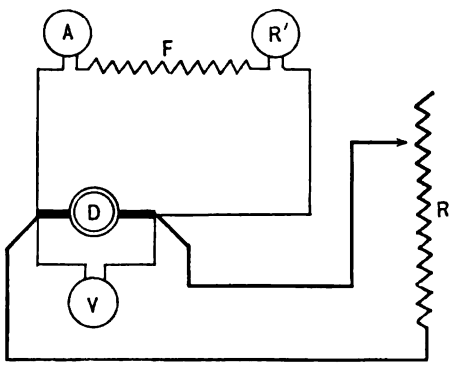


FIG. 215.—Connections for Obtaining Armature Characteristic.

resistance of the armature and the E. M. F. due to residual magnetism. If the field excitation is gradually reduced from a high value to zero, the E. M. F. due to residual magnetism will have a higher value than when the circuit is suddenly broken.

The increase in resistance of the field coils due to increase in temperature affects the resulting curve as does also self-induction and armature reactions and as every effect has its cause, much may be learned by the experimenter in taking these curves.

Armature Characteristic.—This is a curve that shows the relation between the external current and the field current when the difference of potential at the terminals is kept constant and is useful in studying the compounding of a generator, the departure of

the curve from a straight line showing the change in the field current to be compensated for by series turns on the shunt machine.

The connections for making the test is shown in Fig. 215.

An ammeter is connected in the field circuit and the usual variable resistance R in the external circuit.

Instructions.—Adjust the E. M. F. at the brushes with the external circuit open to the value at which the difference of potential is to be kept constant. Then close the external circuit through the maximum resistance used, adjust the field regulator so as to give the same E. M. F. as before and then read A and V. Change

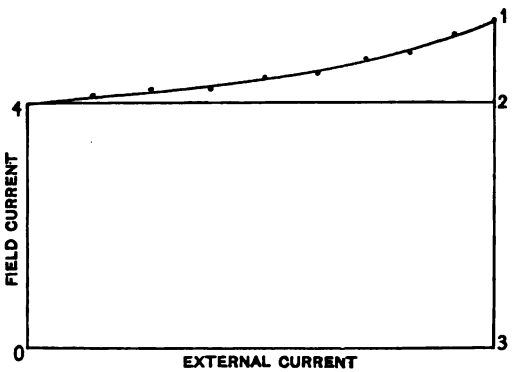


FIG. 216.—Armature Characteristic.

the resistance R slowly, adjust the E. M. F. to its constant value, and read A and V. The curve will have the general form shown in Fig. 216.

The distance 1, 2 on the scale of field current shows the field current that must be added by series turns to produce an E. M. F. of the external current 03 equal to the original E. M. F. producing field current 04.

Characteristics of a Compound Generator.—The compound machine, being merely a shunt generator with the addition of a series field of a few turns, may be used as a shunt generator by leaving out the series coils. The connections are then made and the *external* and *internal* characteristics are then obtained as previously described under the shunt generator.

To obtain the series characteristic the shunt field is disconnected and the procedure is the same as given under the Series Generator.

Compound Characteristic.—The connections for obtaining the data for plotting the compound characteristic curve is shown in Fig. 217.

This shows a "long shunt" machine with the voltmeter V connected across both armature D and series field F' and the ammeter in the external circuit.

Instructions.—Before closing the external circuit adjust the E. M. F. to the same value as that for the external shunt characteristic, so the two curves will start from the same point on the

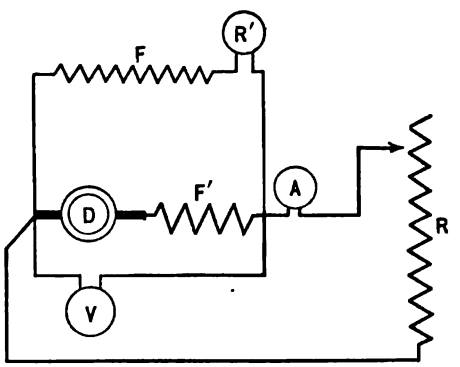


FIG. 217.—Connections for Obtaining Compound Characteristic.

ordinate axis. When the field regulator is once adjusted to give the proper voltage do not change it during the experiment.

Close the external circuit through a resistance that will give a small current and take simultaneous readings of A and V, and at same time take the speed to reduce the voltage to the normal speed. Proceed by small changes in the resistance R and obtain values for A and V.

By disconnecting the series coils and connecting them so that the current through them is reversed, the **differential curve** is obtained. As the field is weakened by increase of current in the series coils, which oppose the shunt, the curve drops more rapidly than the external shunt and the maximum current is much smaller.

Curves showing the relative differences between the characteristics of a compound generator are shown in Fig. 218.

Variation of Speed.

The allowable variation of armature speed of dynamo electric machines under different conditions of load and temperature depends on the kind of work for which they are designed. Modern well-designed machines should show very close regulation of speed,

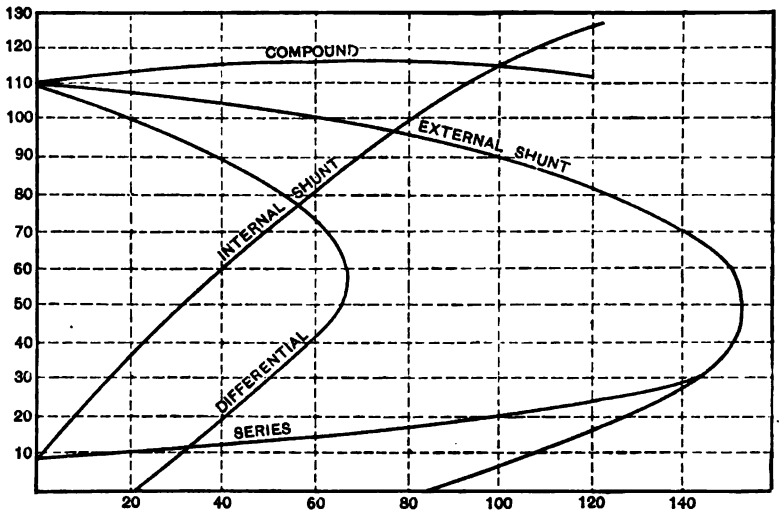


FIG. 218.—Characteristic Curves of a Compound Generator.

and as illustrating the amount of variation considered to be practical, the specifications for machines used on ships of the navy are quoted.

For main generators the speed variation must not exceed 2½ per cent when load is varied between full load to 20 per cent of full load, gradually or in one step, engine running with normal steam pressure and vacuum. A variation of not more than 3½ per cent is allowed when full load is suddenly thrown on or off the generator, with constant steam pressure, either normal or 20 per cent above normal. A variation of not more than 3½ per cent is

allowed when 90 per cent of full load is suddenly thrown on or off the generator, with constant steam pressure at 20 per cent below normal; exhaust in both cases to be either into condenser or atmosphere.

For shunt-wound motors, the variation in speed from no load to full load is not allowed to be more than 12 per cent in motors of less than 5 horsepower and not more than 9 per cent in motors of 5 horsepower and above. Series and compound-wound motors must make their rated outputs at their rated speeds. The motor must be designed to obtain its rated speed when hot, with atmospheric temperature of approximately 25° C., and the speed actually obtained at the end of a heat run must be within 4 per cent of the rated. The variation in speed due to heating should not exceed 10 per cent.

For motor generators of a speed of about 2000 revolutions per minute, such as used for gun-elevating equipment, the speed variation between no load and full load and from full load to no load should not exceed 10 per cent of normal. For those of about 1500 revolutions per minute, used in turret-turning equipment, the variation between no load and full load and from full load to no load should not exceed 6 per cent of normal.

For motors for driving machine tools, the variation in speed from no load (hot) to full load (hot) shall not be more than 9 per cent in motors of less than 5 horsepower and not more than 7 per cent in motors of 5 horsepower and over. For all motors the variation from their rated speeds at full load (hot) must not exceed 5 per cent and the variation in speed due to heating must not exceed 10 per cent. For variable speed motors these conditions must be met at any set speed throughout the range.

Dielectric Strength and Insulation Resistance.

There are two distinct properties which the insulation of a completed machine should possess: first, its ability to withstand the application of a high voltage for a long time without deterioration, its *dielectric strength;* second, its ability to offer a sufficiently high resistance to prevent any appreciable leakage in working, its *insulation resistance.*

The insulation of a generator or motor should first be tested by the application of an alternating E. M. F. 5 to 10 times the working pressure of the machine, applied between one of the main terminals and the frame. This will make sure that all conductors are insulated from the iron parts of the machine. Naval specifications for generators and motors require the test for dielectric strength to be made at the end of a heat test with pressures of at least 1500 alternating volts to be applied for a continuous period of one minute, the source of power to be either a generator or transformer of at least 5 kilowatts capacity.

Several methods of measuring insulation resistance are given in the chapter on Measurements and also in the chapter on Care of Electric Plant and Accessories, but specifications for modern machines require a testing voltage of at least four or five times the difference of potential ordinarily to be withstood. The insulation between all parts should be at least one megohm.

Heating.

The heat produced in the conductors of electric machines, in the armature and field windings, commutator segments, in the iron frame work, the field frame, spools and pole pieces, bearings, etc., is energy lost and consequently it is the aim to reduce these losses to a minimum. Different rises of temperature are allowed in different classes of machines, depending on their construction and their location, the general limits being between about 30° C. to 60° C. after four hours' continuous running at full load. The rise in temperature in enclosed motors is allowed to be about 10° C. greater than in open motors.

For generators used in the navy the maximum allowable rise in degrees C. is armature 33⅓°, commutator 40°, field coils 33⅓° above a standard room temperature of 25° C.

Rise of Temperature.—It is usual to measure the rise of temperature in the armature and field coils by means of the change of their resistances due to the heat produced and in the commutator and other parts by means of a thermometer.

By Thermometer.—In using the thermometer great care should be used to see that the bulb is well protected by waste or some such

covering to prevent radiation and that the highest temperature is taken. It is obviously impossible to measure the temperature of coils by a thermometer with any degree of accuracy whatever, as the inner layers, which experiment always shows are the hottest, cannot be reached by ordinary thermometers. Difficulty would also be found in getting the hottest part of outside layers as some parts would be cooled by the moving armature more than others.

The thermometer should have a long thin bulb and be placed flat against the surface with as much bearing surface as possible, and well covered with some non-conducting material and if possible should be read in this position.

By Change of Resistance.—To measure the rise in temperature of armature or field conductors, their resistances are measured, as already given, both when hot and cold; that is, the resistances are measured when the machine is at rest and again after four or five hours' continuous run at full load and before they have had time to cool.

Method of Calculation.—The method of calculation in general use and required by navy specifications is that based upon the report of the Committee on Standardization of the American Institute of Electrical Engineers and is as follows:

1. In computing the temperature rise of a coil by change of resistance, the following method should be used:

(a) The total rise in temperature of a coil during a test to be determined by the formula adopted by the American Institute of Electrical Engineers, viz.:

$$\theta = (238 + t)\left(\frac{R_{(t+\theta)}}{R_t} - 1\right)$$

where θ = total rise of degrees Centigrade,

t = cold temperature of the coil,

R_t = cold resistance of coil,

$R_{(t+\theta)}$ = hot resistance of coil,

also let T = final room temperature;

and by the use of this formula it is assumed that .0042 is the temperature coefficient of copper from and at 0° C.

(b) From the total temperature rise calculated as above, subtract the difference between the cold-coil temperature t and the

final room temperature T, which should be carefully taken as directed below.

(c) The rise thus obtained above final room temperature to be corrected by one-half of 1 per cent for each degree Centigrade that the final room temperature differs from 25° C. The correction to be added if the room temperature is below 25° C., and subtracted if above it.

In the case, however, of shunt-wound coils subjected to a constant potential, the current strength and therefore the temperature rise will be changed by a change of room temperature. A correction for this should be made by correcting the rise, as above calculated, in proportion as the final absolute temperature of the room differs from the absolute temperature at 25° C. In most cases this correction nearly neutralizes the correction under (c); both corrections are, however, recommended by the American Institute.

2. In connection with the above method, the following instructions should be carefully observed:

(a) The temperature t should be taken by a thermometer placed directly on the coil, at the time the cold resistance is taken, and has nothing to do with the cold-room temperature. In taking this cold-coil temperature care should be taken that the coil has not been recently brought from a much colder or hotter place than that in which the test is being made.

(b) The room temperature T, above which the temperature rise of the machine is calculated, must be very carefully determined. The temperature of the room should be read from a thermometer placed in such a position that it fairly represents the temperature of the air surrounding the machine. If the room temperature remains constant during the run there will be no question as to the final room temperature; if the temperature varies, however, as is usually the case, for a short run of two hours or less, the average of the entire run should be taken; for a run of six hours or more the average of the last three hours should be taken. Conditions should be such that the room temperature will not vary greatly during the tests, and a variation in room temperature of over 10° C. during a heat run of six hours, or a proportionate change for runs of shorter duration, should in no case be exceeded. If, however, the

temperature is very irregular throughout the run, or changes rapidly at the end, the test should be made over, especially if the machine is near the heating limits of the specifications.

(c) To prevent the sudden fluctuation of room temperature due to the opening of doors, etc., it is recommended that the bulb of the thermometer registering the room temperature be inserted in a hole drilled in a small iron block, the hole to be filled with cylinder oil or mercury. This block can be conveniently made of about the following dimensions: Three inches in length, 2 inches in diameter, with a $\frac{1}{2}$-inch hole, drilled $1\frac{1}{2}$ inches in depth. Care should be taken that the machine under test is not exposed to drafts of air.

3. An example of the above follows:

Length of heat run = 6 hours. The last seven half-hour readings of room temperature are, 19.5, 20, 20.5, 21, 21.5, 22, and 22.5; average, 21° C. = T.

The cold resistance of coils = 150 ohms = R_t.

The hot resistance of coils = 180 ohms = $R_{(t+\theta)}$.

The cold temperature of the coils is 15° C.

Then $\theta = (238 + 15)\left(\frac{180}{150} - 1\right) = 50.6°$ = rise above cold-coil temperature.

The variation from cold-coil temperature to final room temperature is 6 degrees. Then 50.6° — 6° = 44.6° rise above room temperature. The difference between final room temperature and 25° C. is 25° — 21° = 4°. Therefore, 4 times $\frac{1}{2}$ per cent equals 2 per cent correction, or $44.6 \times 1.02 = 45.49°$ rise above room temperature corrected to 25° C.

If the coils were shunt-wound constant-potential coils, the rise should be again corrected in the ratio of 238 + 21° and 238 + 25°, or a rise of 44.79°.

4. In computing temperature rises from thermometer measurements, the rise should be figured above final room temperature T taken as explained in paragraph 2 (b) above, and corrected as directed in paragraph 1 (c) above.

Efficiency.

The question of efficiency of generators has been treated in the chapter on Efficiencies and Losses of Generators and of motors in the chapter on Motors. The efficiency of generating sets should be as high as practicable consistent with good design and the specific requirements, but where thorough reliability and freedom from danger of breaking down are the first requisites, as in motors for turning turrets, elevating guns, hoisting ammunition, hoisting boats, etc., maximum efficiency is often sacrificed to reliability.

The commercial efficiencies required for the main generators installed on ships of the navy are given in the following table:

K. W.	Loads.			
	1⅓.	1.	¾.	½.
	Per Cent.	*Per Cent.*	*Per Cent.*	*Per Cent.*
2.5	78	78	76	73
5	80	80	78	75
8	83	83	81	77
16	87	87	86	84
24	88	88	87	85
32	88	88	87	85
50	89	89	88	86
100	90	90	89	87

Commercial Efficiency of Generators.—The commercial efficiency is determined by finding the ratio between the power utilized in the external circuit and the total power supplied to the engine of the generator, both expressed in the same units.

The methods used for determining the efficiency are of two kinds:

(1) Methods in which the driving power and the electrical output are both separately measured. These are called *direct* methods.

(2) Methods in which the losses in the generator are determined by electrical measurements. These losses added to the output gives the power supplied to it. These are called *indirect* methods.

Direct Method.—For any given load the power utilized in the external circuit is found by inserting an ammeter in the circuit and connecting a voltmeter to the terminals of the machine. Indicator cards are taken from all cylinders at the same time and the revolutions of the engine are taken.

From the indicator cards, the mean effective steam pressure is

found, and with the area of piston, length of stroke and number of revolutions, the indicated horsepower is found from the formula

$$\text{H. P.} = \frac{plan}{33{,}000}, \qquad (1)$$

where p = mean effective pressure in pounds per square inch,
l = length of stroke in feet,
a = area of piston in square inches,
n = number of revolutions per minute.

Dividing the product of the volts and amperes of the external circuit by 746 expresses the external energy utilized in horsepower, thus

$$\text{H. P.} = \frac{eC}{746} \qquad (2)$$

and the commercial efficiency $= \frac{(2)}{(1)}$.

Indirect Method.—In this method the losses in the generator are found and the efficiency is calculated from the formula

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{losses}}.$$

The output is as before directly measured by means of a voltmeter and ammeter properly connected in the external circuit. The losses are partly calculated and partly found by experiment.

The calculated losses are those due to power spent in overcoming the field and armature resistances. In each case and for each particular part, the loss in watts is equal to the square of the current multiplied by the resistance, or

$$\text{watts} = C^2R.$$

Thus, for the

armature loss, $W = C^2_a r_a$;
series-field loss, $W = C^2_m r_m$;
shunt-field loss, $W = C^2_s r_s$; etc.

The losses found by experiment are those due to

Friction of the bearings, brushes, air friction.
Eddy currents in the armature core.
Hysteresis losses in the armature core.

These losses can be determined by running the generator as a motor with no load, separately exciting the field to its normal extent and supplying the armature with current sufficient to make it run at the same speed it did when running as a generator; or, in other words, sufficient to impart to the armature terminals an E. M. F. equal to the *total* E. M. F. generated when run as a generator.

The efficiency of a motor is the ratio of the input to the output, or

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{input} - \text{losses}}{\text{input}}.$$

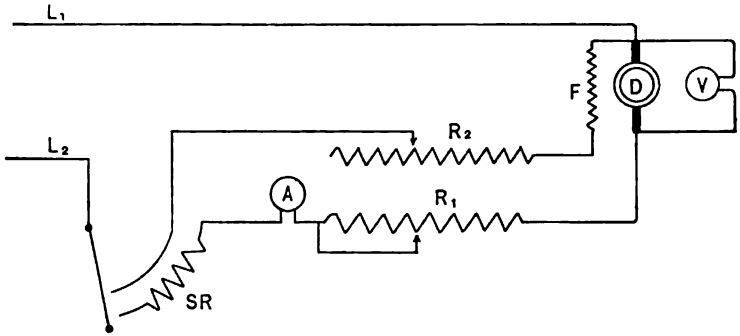


FIG. 219.—Connections for Swinburne's Test.

When the generator is run as a motor with no load and separately excited, the efficiency is zero, or

$$\text{input} = \text{losses}.$$

The losses now are the watts lost in the armature, due to the current producing the speed and the other losses referred to. The current and the armature resistance both being so small, the $C^2_a r_a$ is so extremely small as to be negligible, so the input is equal to the losses due to friction, hysteresis and eddy currents.

The input is measured by a voltmeter connected to the armature terminals and an ammeter connected in the circuit.

Swinburne's Test.—The connections for finding the current absorbed when supplied with an E. M. F. equal to that produced as a generator is shown in Fig. 219 and is known as Swinburne's test.

Connections are made as in Fig. 219, in which

L_1L_2 are the supply mains,
D the armature under test,
F the shunt-field coils,
R_1 adjustable resistance for varying voltage at armature terminals,
R_2 adjustable resistance for regulating exciting current,
V voltmeter connected across armature,
A ammeter for measuring armature current,
SR starting rheostat.

Instruction.—With the resistance in R_2 all out, close the switch of SR. This throws in the shunt field and excites it and at the same time sends current through R_1 and the armature D, starting it.

Adjust the resistance in R_1 until the voltage shown on V is equal to that produced when running as a generator. (Note that this E. M. F. must be the total E. M. F. produced, calculated for a shunt generator from $E = e + C_a r_a$, or $E = e + (C + C_s) r_a$.) Measure the speed. If it is not the same as that for which E was calculated, adjust R_2 until the proper speed is obtained.

When running at the proper speed and the voltmeter shows the proper E. M. F. read A, and call it C_A.

The calculation of losses is as follows, the data known from running as a generator being e, C, r_a, r_k:

$$C_s = \frac{e}{r_s},$$
$$E = e + (C + C_s) r_a,$$
$$C_a = C + C_s.$$

Loss in armature $= C^2_a r_a$,
" shunt $= C^2_s r_s$,
" driving $= E \times C_A$.
Total losses $= C^2_a r_a + C^2_s r_s + EC_A$.
Output $= eC$,
Input $= eC + C^2_a r_a + C^2_s r_s + EC_A$.

$$\therefore \text{ Efficiency} = \frac{eC}{eC + C^2_a r_a + C^2_s r_s + EC_A}.$$

This method is applicable to shunt, series or compound generators,

the only difference being in the calculation of the losses in the armature and field, as the current flowing in them will be different in each class of machine.

This indirect method can best be illustrated by an example.

A *short*-shunt compound generator maintains a difference of potential at the terminals of 150 volts at a certain speed and supplies 20 amperes to the external circuit. The resistances are

Armature, .18 ohm,
Series winding, .07 ohm,
Shunt winding, .95 ohm.

Solution: The fall of potential in the series winding $= 20 \times .07 = 1.4$ volts; therefore, the difference of potential at armature terminals $= 150 + 1.4 = 151.4$ volts.

$$\text{Shunt current} = \frac{151.4}{95} = 1.59 \text{ amperes,}$$

$$\text{Armature current} = 20 + 1.59 = 21.59 \text{ amperes.}$$

The fall of potential through armature $= 21.59 \times .18 = 3.9$ volts.

When this machine was connected to run as a motor as in Fig. 219, it was found, when running at the same speed as before, that to produce the total E. M. F. $150 + 3.9 = 153.9$ volts it required .75 ampere.

Loss in armature	$= 21.59^2 \times .18$	$=$	84.8	watts.
" shunt	$= 1.59^2 \times .95$	$=$	240.3	"
" series	$= 20^2 \times .07$	$=$	28.0	"
Other losses	$= 153.9 \times .754$	$=$	116.0	"
Total losses		$=$	469.1	"
Output	$= 20 \times 150$	$=$	3000	"
Input		$=$	3469.1	"

$\therefore$ Efficiency $= \frac{3000}{3469} = 86.4$ per cent.

Commercial Efficiency of Motors.—The commercial efficiency of a motor is the ratio of the mechanical power of the motor to the electrical power supplied to it, both amounts of power being expressed in the same units.

The electrical power supplied to the motor is expressed in watts and is found from the readings of a voltmeter and ammeter properly connected to the supplying circuit.

The mechanical power is usually expressed in terms of horsepower, one horsepower being 33,000 foot-pounds per minute or equal to 746 watts.

The ordinary mechanical means of measuring the power given out by a motor is by some form of brake, or by dynamometer.

Brakes.—Brakes may be of several kinds, the ordinary ones being the *band* brake and *arm* brake.

In the **band** type, the brake is applied directly to a rotating pulley on the motor armature shaft, the pull exerted by the brake being on the surface of the pulley and tangential to it.

In the **arm** brake, the brake is connected to an arm and the pull is exerted at the end of the arm, the brake itself being on the surface of the pulley.

Formula for Brake Horsepower.—Power is the rate of doing work, or the rate of overcoming a force in a given distance.

In the case of a brake, the force overcome is that exerted at the surface of the pulley, due to the turning force of the motor, and is overcome by the friction between the brake and the pulley.

Let f = force in pounds exerted by the brake,
d = diameter of pulley in feet,
n = number of revolutions per minute.

The distance per minute is πd feet, and the work done in n revolutions is $fn\pi d$ foot-pounds, and the power exerted is $\frac{fn\pi d}{33{,}000}$ horsepower.

If the arm brake is used, the force exerted by the brake at the end of the arm is fl, where l equals the length of arm in feet; and the horsepower is $\frac{fln\pi}{33{,}000}$.

Dynamometers.—In all types of brakes, in order to measure the power given out, it is absorbed, but this absorption is not necessary, if some means is provided of measuring the torque.

The torque is the force exerted at the rim of a pulley on the motor shaft and measures its tendency to turn round its **axis.** Numerically it is equal to the force $\times$ the radius of the pulley. The power given out is the product of the torque and speed. The speed is $2\pi n$ feet per minute and the power is

$$fr2\pi n \text{ or } fdn\pi \text{ foot-pounds.}$$

Dynamometers are contrivances for measuring torque and are of two general kinds, **transmission** and **absorption** dynamometers.

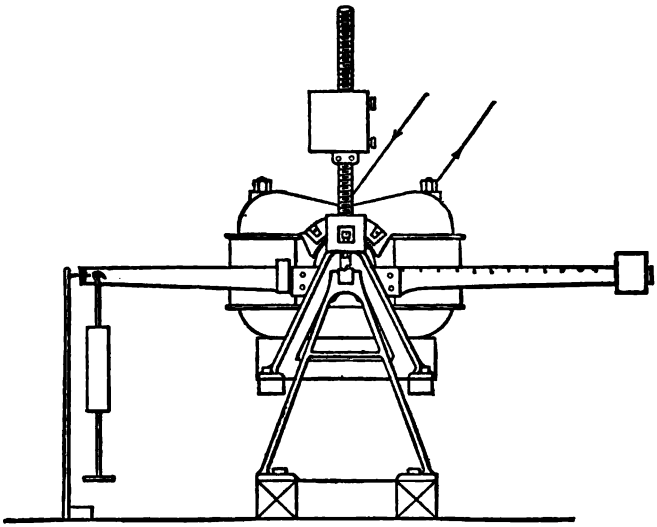


FIG. 220.—Brackett's Cradle Dynamometer.

Brackett's Cradle.—This form of absorption dynamometer is shown in Fig. 220.

The motor is bolted to a small platform which is suspended on a pair of knife edges fixed in a frame, one at each end of the cradle in line with the center of the motor shaft when the latter is properly placed. The cradle has a swinging motion about the axis of the knife edges but is otherwise rigid.

The cradle is fitted with lugs to which may be secured a graduated arm, on which slide known weights. On the cradle are

upright screws on which work different weights, fitting eccentrically on the screw shafts, and by these, the center of gravity of the system may be made to coincide with the axis of suspension, and the cradle can be accurately balanced.

If necessary a belt or cord may be passed around the motor pulley and drawn taut, so as to produce a braking effect to reduce the revolutions, but without tending to disturb the balance on the knife edges.

Measuring the Output.—When the motor is accurately balanced with the weight at the zero of the scale, current may be supplied to the motor. The field will tend to rotate relative to the armature, due to the drag on the armature conductors, and this drag will pull the motor around. It can be brought back to its level position by moving the weight out on the arm, or different weights may be used at different distances to produce the balance.

The torque is equal to the product of the weight and the distance it is from the center of the shaft, or in case more than one weight is used, it is the sum of the products of each weight by its own distance.

As shown above the power exerted, or given out by the motor is

$$\frac{fdn\pi}{33{,}000} \text{ horsepower,}$$

where f = weight on the arm in pounds,
d = distance of weight from center in feet,
n = revolutions of armature per minute.

It is not necessary that the weight shall be at zero when the motor is balanced, but it should be noted where it is, and then knowing the distance it has to be moved to obtain a balance, the torque is the product of the weight and the distance it has been moved.

It is also not necessary that the zero of the scale should coincide with the center of the shaft, for when the first balance is effected, the moment of the weight about the center is counterbalanced by the adjusting weights, so the zero mark of the scale can be placed at any convenient place on the arm.

Determination of Losses.

In the preceding remarks regarding efficiency, it was shown that the difference between the input and output of dynamo electric machines was due to the losses in the machine; and expressed as watts, the loss is equal to the input minus the output, both of course being expressed in watts.

The losses are of two distinct classes; those due to the heat produced in the armature and field windings, produced by the currents flowing through the resistances; and the others due to the heat produced by eddy currents in the iron core of the armature, the hysteresis loss in the same, and the heat caused by friction in the bearings, by the brushes, air friction, etc. The first of these are generally referred to as *copper losses* and are easily calculated, the others are called *iron* and *friction losses.*

The separation of these losses is of greatest importance to the designer, and tells him how best to reduce the total loss. Excessive hysteresis shows inferior quality of iron in the armature core, and large eddy currents shows poor lamination in the core. Large friction losses show inferior lubrication, and possibly improper contact of brushes.

The separation of the iron and friction losses is given here for purposes of experiment, as such work is of great help in procuring a sound understanding of the entire principles governing the construction of electric machines.

Determination of Iron and Friction Losses.—For this experiment make connections as shown in Fig. 219 with the addition of an ammeter in the field circuit, the machine under test to be run as a motor without load. When this is the case there are no copper losses, except the extremely small loss due to the current necessary to drive the armature, which may be neglected as being less than one watt, and all the losses are those due to iron and friction.

The experiment is similar to that for finding the efficiency of a generator (the indirect method) but more observations are taken.

Instructions.—Run the machine for some time (one or two hours) to get everything running smoothly and conductors warmed to a normal extent.

Excite the field to its normal extent, that is by the same current it would have when running at normal speed as a generator. By means of the adjustable resistance R_1 (Fig. 219) get a small voltage at the armature terminals, and with the exciting current constant, take readings of the armature voltage, armature current and speed.

Always keeping the exciting current constant, increase the armature voltage, then make same readings as before. Do this for gradually increased voltage till the full voltage is obtained.

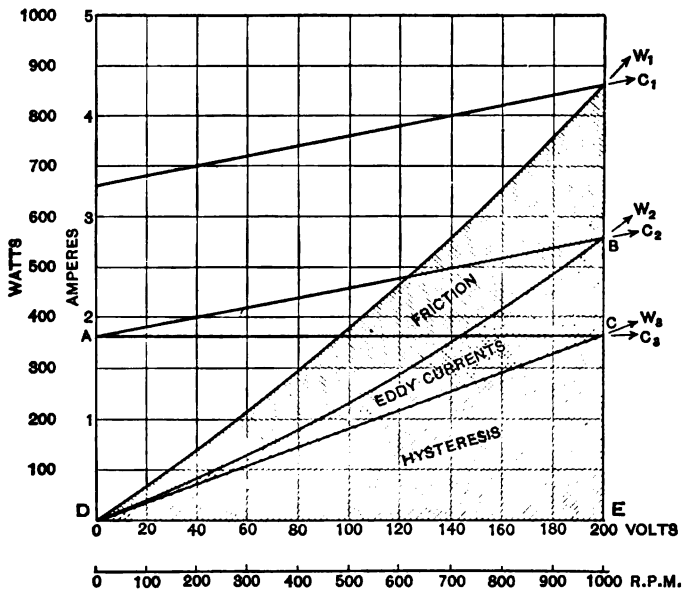


FIG. 221.—Curves Showing Separation of Losses.

Construction.—With the two variable quantities, armature voltage and armature current, plot points to some convenient scale, making volts as abscissæ and amperes as ordinates and draw a curve through the points so determined.

Such a curve is shown in Fig. 221 marked C_1.

As the armature current is directly proportional to the voltage at the terminals, the relation between the current and voltage is

constant and therefore the equation to the curve is of the form $y = mx + c$, c being the distance the line starts above the axis of volts.

Since the speed and voltage are proportional with a constant excitation, a scale of revolutions per minute may be added. In the example assumed 1000 revolutions per minute correspond to 200 volts.

The iron and friction loss, or **no-load loss curve** can now be plotted. This is done by plotting the volts as abscissæ and the product of volts and amperes as ordinates, a scale of watts being marked to a convenient scale on the left. Thus for volts equal to 40, the current is 3.5 amperes, and the watts $40 \times 3.5 = 140$. This is plotted with 40 as abscissa and 140 as ordinate. Similarly other points on the curve are plotted and the curve W_1 drawn through them.

The ordinates of this curve for any speed will show the "no-load" loss at that speed.

Determination of Friction Losses.—The loss due to friction of the brushes and of the bearings increases in direct proportion to the speed of the armature, while the air-friction loss varies almost as the square of the speed.

If the armature could be run without any field, there would be no iron losses, and the only loss would be that due to friction, so the method employed to determine the friction loss is to estimate the power required to run the armature without field.

By observing the current and voltage necessary to keep the speed constant, a curve of watts can be plotted to show the no-load loss over a considerable range of field excitation. These curves can be plotted for different speeds and then an estimate can be made of what the losses for different speeds would be if the field excitation was zero, which would be the reading of the watts for zero voltage; found by prolonging the curves for the speeds until they cut the axis of watts.

A set of these curves are shown in Fig. 222 in which the same scale is used as in Fig. 221, but are plotted separately to avoid confusion.

The data for these curves is found by using the same connections

as in the previous experiment and shown in Fig. 219. The excitation of the field is varied by the resistance R_2 and the armature voltage is adjusted to maintain the speed constant by adjusting R_1. For the given speed take reading of the exciting current, armature volts and amperes. Reduce the exciting current, keeping the speed constant by R_1 and take readings as before. Repeat this operation for the constant speed, reducing the exciting current to as low value as can be employed.

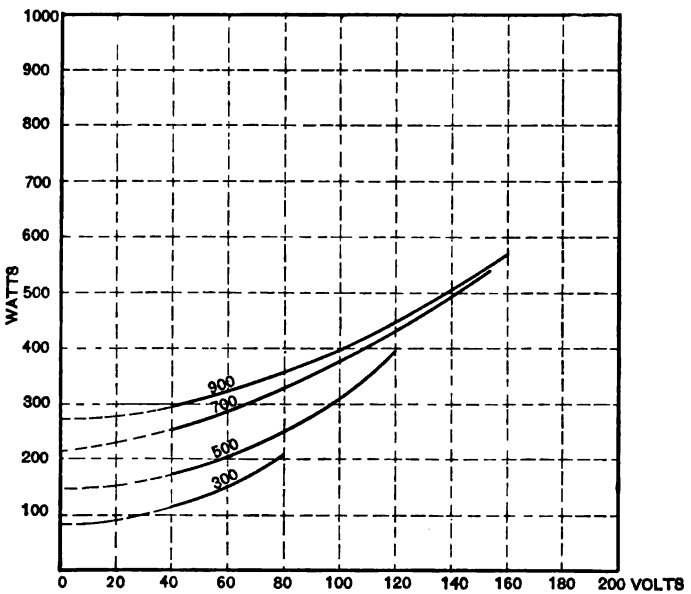


FIG. 222.—Curves of No-Load Loss.

With a new speed, repeat the operation, getting as many points on the curve as possible, especially with the low exciting current.

For each set of observations, one set for each speed, find the watt curve or the product of armature volts and amperes, and with the volts as abscissæ and watts as ordinates, plot a series of points for each speed, and through these points draw fair curves.

The ordinates of these curves for any armature voltage will give the "no-load" loss for the different speeds.

These curves are continued until they cut the axis of watts at zero voltage, in which case the ordinates at zero voltage will give the friction losses for those speeds.

Remembering that the curve W_1 (Fig. 221) represents the total no-load loss, the friction losses found from the curves on Fig. 222 can be transferred to it, and subtracting the friction losses from the total loss for the corresponding speed, the remainder will be the total iron losses. This will give curve W_2, the ordinates intercepted between curves W_1 and W_2 being the friction losses for the different speeds or different armature voltage.

From curve W_2, which is the **watt curve of iron losses,** the current curve C_2 can be plotted by dividing each ordinate (watts) by the corresponding abscissæ (volts), using for points on the curve, volts for abscissæ and amperes for ordinates. This curve will be a straight line for the same reason as given for curve C_1.

Where the curve C_2 cuts the axis of watts, draw a horizontal line C_3. This line divides the ordinates of the current line C_2 into two parts, the portion below the horizontal line representing the current required to overcome the hysteresis loss, and the portion intercepted between the horizontal line and curve C_2, the current required to overcome eddy-current losses.

The area of the triangle $ABC = \frac{1}{2} BC \times AC$,

$$\frac{BC}{AC} = \tan \alpha, \quad \therefore \text{ area} = \tfrac{1}{2} AC^2 \tan \alpha,$$

and is therefore proportional to the square of the voltage and consequently to the square of the speed. Since eddy losses increase in proportion to the square of the speed, the area must represent the power necessary to overcome them. The area $ACED$ is proportional to DE, $\therefore$ to the voltage and to the speed, and as hysteresis is proportional to speed, this area represents the power necessary to overcome the hysteresis loss.

From the last curve C_3, find the watts spent in overcoming hysteresis, by multiplying the current ordinate by any voltage within the limits of experiment, and drawing a straight line through this point to the origin.

The losses are now completely separated and are as shown in Fig. 221. The friction losses are represented by the ordinates for

any voltage (or speed) between the two curves W_1 and W_2; the eddy-current loss by the ordinates between W_2 and W_3 and the hysteresis loss by the ordinates between W_3 and volt line, and the sum of course equals the total friction and iron loss for any voltage.

Example.

The foregoing separation of losses may be made clearer by an example with assumed values to illustrate the experiment, the values taken being those used to plot figure 221.

In the first part of the experiment, keeping the exciting current constant and varying the voltage, the following values were obtained in columns I and II.

I. V (volts).	II. C (amperes).	III. VC (watts).
40	3.5	$40 \times 3.5 = 140$
80	3.7	$80 \times 3.7 = 296$
120	3.9	$120 \times 3.9 = 468$
160	4.1	$160 \times 4.1 = 656$
180	4.3	$180 \times 4.3 = 860$

Curve C_1 was plotted with the values given in columns I and II, and curve W_1 with values in columns I and III.

In the second part of the experiment, the friction loss, the following data was obtained by keeping the speed constant for a series of readings and observing the armature volts and amperes, the observed data being given in the second and third columns of the four tables, *A, B, C* and *D*.

A				B			
I. Revs.	II. V.	III. C.	IV. VC.	I. Revs.	II. V.	III. C.	IV. VC.
900	160	3.6	576	700	160	3.6	576
900	120	3.8	456	700	120	3.6	432
900	80	4.5	360	700	80	4.2	336
900	40	7.5	300	700	40	6.5	260

C				D			
I. Revs.	II. V.	III. C.	IV. VC.	I. Revs.	II. V.	III. C.	IV. VC.
500	120	3.3	396	300	80	2.6	208
500	80	3.1	248	300	40	3.0	120
500	40	4.5	180				

The four curves of Fig. 222 were plotted from the data of columns II and IV.

These curves were then prolonged until they cut the vertical axis, the ordinates of which gives the friction loss in watts. These values are from the curves:

Revs.	Friction watts.
900	270
700	210
500	150
300	90

To Plot Curve W_2.—On ordinate corresponding to speed of 900 revolutions subtract the friction loss for that speed, thus

For 900 revolutions (180 volts) $755 - 270 = 485$
700 " (140 ") $560 - 210 = 350$
500 " (100 ") $380 - 150 = 230$
300 " (60 ") $215 - 90 = 125$

With the values in the last column of the above table and volts corresponding to the speed of the first column, plot curve W_2.

To Plot Curve C_2.—Divide the values in the last column of the above table by the voltage corresponding to the speed, thus

VC.	V.	C.
485	÷ 180	= 2.7
350	÷ 140	= 2.5
230	÷ 100	= 2.3
125	÷ 60	= 2.1

With the values of V and C of the above table, plot curve C_2. This will be a straight line parallel to C_1 for the differences of their ordinates is a constant quantity; thus ordinate of C_1 corresponding to 180 is 4.2, to 140 is 4.0, to 100 is 3.8 and 60 is 3.6. The differences of the ordinates is then

$4.2 - 2.7 = 1.5$
$4.0 - 2.5 = 1.5$
$3.8 - 2.3 = 1.5$
$3.6 - 2.1 = 1.5$

To Plot Curve C_3.—This has already been explained.

To Plot Curve W_3.—The ordinate of C_3 is the difference between that of C_1 for zero voltage and the differences of the ordinates of C_1 and C_2, or 3.3 — 1.5 = 1.8 amperes.

For 20 volts then the watts are equal to

	20×1.8	amperes	=	36	watts,
and	40×1.8	"	=	72	"
"	60×1.8	"	=	108	"
"	80×1.8	"	=	144	"
"	100×1.8	"	=	180	" etc.

As there is a constant difference the line is straight and can be determined by taking any convenient voltage, finding the watts, and plotting the point with volts and watts and drawing a straight line to the origin.

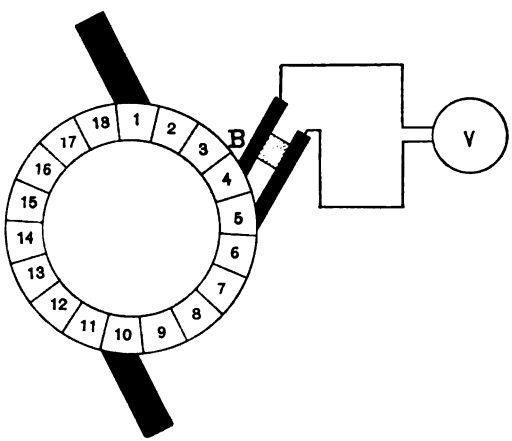


FIG. 223.—Exploring E. M. F. Around Armature.

Determination of E. M. F. Around Armature.

The object of this test or experiment is to show the distribution of potential differences around the armature. If the difference of potential is measured between the negative brush and successive bars of the commutator it will be found that in a well-designed machine the difference of potential increases regularly, though not equally, in both directions, becoming a maximum when the position of the positive brush is reached. In badly-designed machines the distribution will be found to be irregular.

One way of attaining the differences of potential is to measure the voltage induced in the coils connected between individual pairs of commutator segments at different points around the circumference. There are two methods in general use of making these measurements, depending on the relative position of the individual pairs of commutator segments to which the measuring instrument is connected.

Two-Brush Method—S. P. Thompson Method.—If the difference of potential between successive segments is required the simplest method is to use two small brushes insulated from each other and fixed apart a distance equal to that between successive commutator

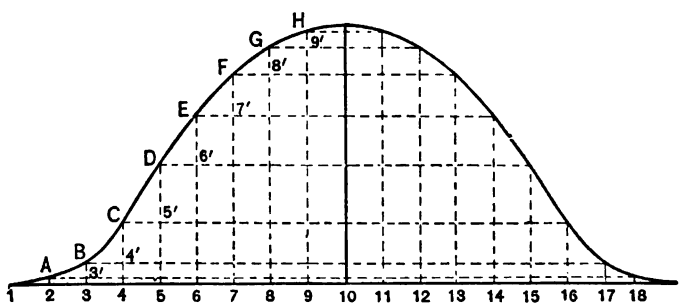


FIG. 224.—Curve of Total Difference of Potential.

segments, the brushes connected to a low-reading voltmeter. The connections are shown in Fig. 223.

By moving the small auxiliary brushes *B* around the commutator the difference of potential is measured on the voltmeter *V* between any two successive segments on which the brushes make contact.

The results may be plotted in the form of a curve which will show the total difference of potential between brushes or between one brush and any particular segment as well as the difference of potential between successive segments. Such a curve is shown in Fig. 224.

In Fig. 224 the position of the negative brush is shown at 1 and the positive brush at 10, and the commutator segments are numbered consecutively from 1 to 18. If the exploring brushes are pressed against segments 1 and 2, the resulting E. M. F. would be

plotted, according to some convenient scale, as an ordinate equal to $2 - A$. If connected to 2 and 3, the resulting E. M. F. is plotted as $3' - B$. To this must be added that due to $1 - 2$, which is $3 - 3'$. In other words, following consecutively around the commutator, the resulting E. M. F. should be added to the total E. M. F. up to that point, and in this way the whole curve is constructed; after leaving the positive brush, the resulting differences of potential will be subtractive from the preceding one.

Single-Brush Method—Mordey's Method.—A more general method of attaining the same result is to use only the auxiliary contact brush, to which the terminal of the voltmeter is connected, the other terminal being connected to one of the main brushes of the machine. By moving the auxiliary brush from one segment to another, the difference of potential is measured from the machine brush to the segment, and to obtain the difference between any two segments it is only necessary to subtract the differences of potential between the main and auxiliary brushes, when the latter is connected to consecutive segments.

In using two auxiliary brushes, the voltmeter may be a low-reading one, as the greatest difference of potential is only that between two successive coils, but the single-brush method requires a voltmeter to register the complete voltage of the armature.

The results obtained by the single-brush method can be plotted in a curve exactly similar to that shown in Fig. 224. When the auxiliary brush is connected to segment 2 the resulting voltage can be plotted as $A - 2$; when on segment 3 as $3 - B$, etc.

To obtain the difference between any two consecutive segments, or in fact, any two segments, it is only necessary to subtract the ordinates corresponding to the segments desired.

Practical Arrangement of a Single-Brush Method—Joubert's Method.—A practical method devised by Joubert for examining the E. M. F. induced at successive points on the commutator is shown in Fig. 225.

D and *E* are two wooden discs fitted around the armature shaft and can be secured in any position relative to each other. One of these is fixed to the shaft and the other is carried by it. The disc *E* is fitted with a continuous metal rim to which is connected a

small spring *F* which presses against the commutator. Let into the rim of *B* is a contact plate *C* which has a small tongue which is in contact with the metal rim of *E*. The auxiliary brush *B* is fixed and rubs against the rim of *D*, making contact with *C* once in each revolution.

When *C* passes under the brush *B*, the circuit is completed through the voltmeter *V*. By shifting *D* and *E* relatively to each other, *C* and *F* are brought relatively nearer together or further apart, so connection can be made between any two segments of the commutator. This device can be so arranged that when *C* is pass-

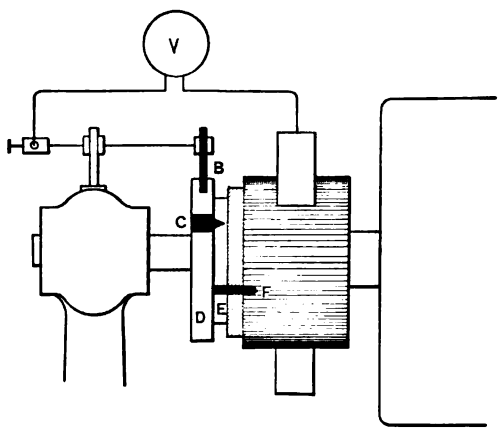


FIG. 225.—Illustrating Joubert's Method of Exploring E. M. F.

ing under *B*, *F* makes contact with the adjoining segment to that under the main brush of the machine, so the voltage obtained will be that between the main brush and its adjoining segment. By shifting *F* ahead the angular distance of one segment at a time, the voltages will be measured consecutively around the commutator from the common brush.

Owing to the fact that the contact of the brush *B* with the contact piece *C* is momentary and intermittent, an ordinary voltmeter would oscillate rapidly, or if it was absolutely dead beat, it would indicate a mean lower voltage than that corresponding to the voltage at the instant of contact. For accurate results, it is better to use

an electrostatic voltmeter with a condenser connected in parallel, as the voltmeter would probably have so small a capacity that it would discharge itself too rapidly to affect the slow-moving needle. A hot-wire voltmeter specially calibrated can be used to good advantage.

In making the test, it is well to connect another voltmeter to the machine terminals, and by means of a regulator in the shunt field, keep the voltage of the machine constant during the test.

One experiment can be made with no load on the machine and another with full load, and the differences in the resulting curves

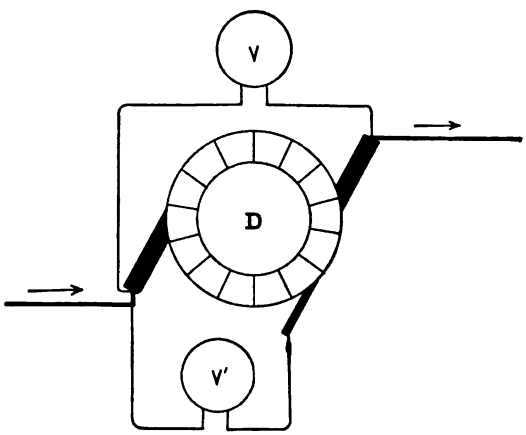


FIG. 226.—Fall of Potential Around Armature.

of E. M. F. will show the effect of the armature current on the field distribution.

Fall of Potential Around a Stationary Armature.—In the above methods, the fall of potential around the commutator has been measured by the current produced by the armature itself, but to test the similarity of windings in the different sections of an armature, an outside source of current can be used and the fall of potential due to the resistance of the armature windings can be tested.

Connections are made as in Fig. 226.

The brushes of the stationary armature *D* are connected to an

outside source of current and a strong current is sent through the armature and a voltmeter V connected to the brushes will show the total fall of potential through the armature windings. Another voltmeter V' is shown connected one terminal to one brush, the other to any segment of the commutator.

If the armature is sound and the windings similar there should be the same fall of potential from the leading-in point to segments each side equally distant from it, and the fall of potential should be the same from one segment to another. If it is not, it indicates a fault of some kind in the winding, and this method can be used to locate short circuits, as a short-circuited coil would show no change of difference of potential from its adjoining coil.

CHAPTER XXII.

MOTIVE POWER FOR GENERATORS.

The only motive power that has been used on board ships of the navy for driving electric generators is steam, with the exception of that for motor generators, which is, of course, electric power. Experiments were made at one time with water motors as a source of power for generator driving, and although good results were obtained it never was adopted or tried under service conditions.

Steam Installation.—The installation of the steam power for driving electric generators is usually separate and distinct from all other steam-driven machines. Steam pipes are lead direct from certain boilers, or all of them, and at each boiler there is fitted a separate boiler stop valve, so boilers not in use may be entirely cut off. The steam pipes from the boilers lead to a common steam pipe at which they are fitted with stop valves. This common pipe is generally connected with the auxiliary steam pipe system of the ship, but steam from this system is not used if it can be avoided, it being generally preferable to use steam direct from the working boilers.

The common steam pipe enters the dynamo-room, where the steam passes through a reducing valve to reduce the boiler pressure to that of the working pressure of the generator engines. From there it passes through a steam separator, in which any water is separated from the steam, and from the separator, branch pipes controlled by stop valves lead to each engine. In ships having dynamo-rooms on different decks, it is usual to install the reducing valve and separator on the lower deck, in which case steam riser pipes lead to the upper rooms, although each room may be fitted with its own reducer and separator. At the engine the steam is controlled by a steam stop valve and in addition a throttle valve. In a compound

engine, after passing the throttle valve, steam enters the high-pressure steam chest, where it is controlled by the high-pressure steam valve, usually of the piston type. Steam enters the high-pressure cylinder where the first stage of the expansion is carried out, and when the pressure has somewhat fallen owing to the expansion and work that has been done, it is exhausted into an intermediate receiver and from there passes into the low-pressure valve chest, where it is controlled by the low-pressure valve, usually of the slide type. After passing this valve the steam passes into the low-pressure cylinder, where it acts on the low-pressure piston and the second stage of the expansion is carried out. After it has done its work on the piston and the pressure has fallen, it is exhausted through an exhaust pipe, controlled by an exhaust valve at the engine, and the steam now fallen to the pressure in the exhaust line is carried to an auxiliary condenser where it is condensed to the form of water. The condensed steam in the form of water is now returned to the boiler by feed pumps which draw the water from the hot well, to which it has been drawn by the air pump by which the vacuum in the condenser is maintained. The object of the condenser is to save the water and the heat in the exhaust steam, and the air pump is to reduce the pressure against which the steam acts in the cylinders of the engine and to remove the condensed steam from the condenser.

The dynamo exhaust line may be connected to an auxiliary exhaust line, but this should not be used except when necessary, as the vacuum is generally poor, owing to its long length of pipe and numerous joints in which leaks may occur. The connection to any exhaust line except the main or auxiliary condensers may lead to back pressures which seriously affect the speed of the engines.

The exhaust line is also fitted to exhaust into the atmosphere if for any cause the condensers cannot be used, as when in dry-dock.

The path of steam from the boiler through the generator engine and back to the boiler is shown in Plate I. Ordinarily the condenser with its fittings and pumps is not installed in the dynamo-room as shown, but in the engine-room to which the exhaust pipe leads.

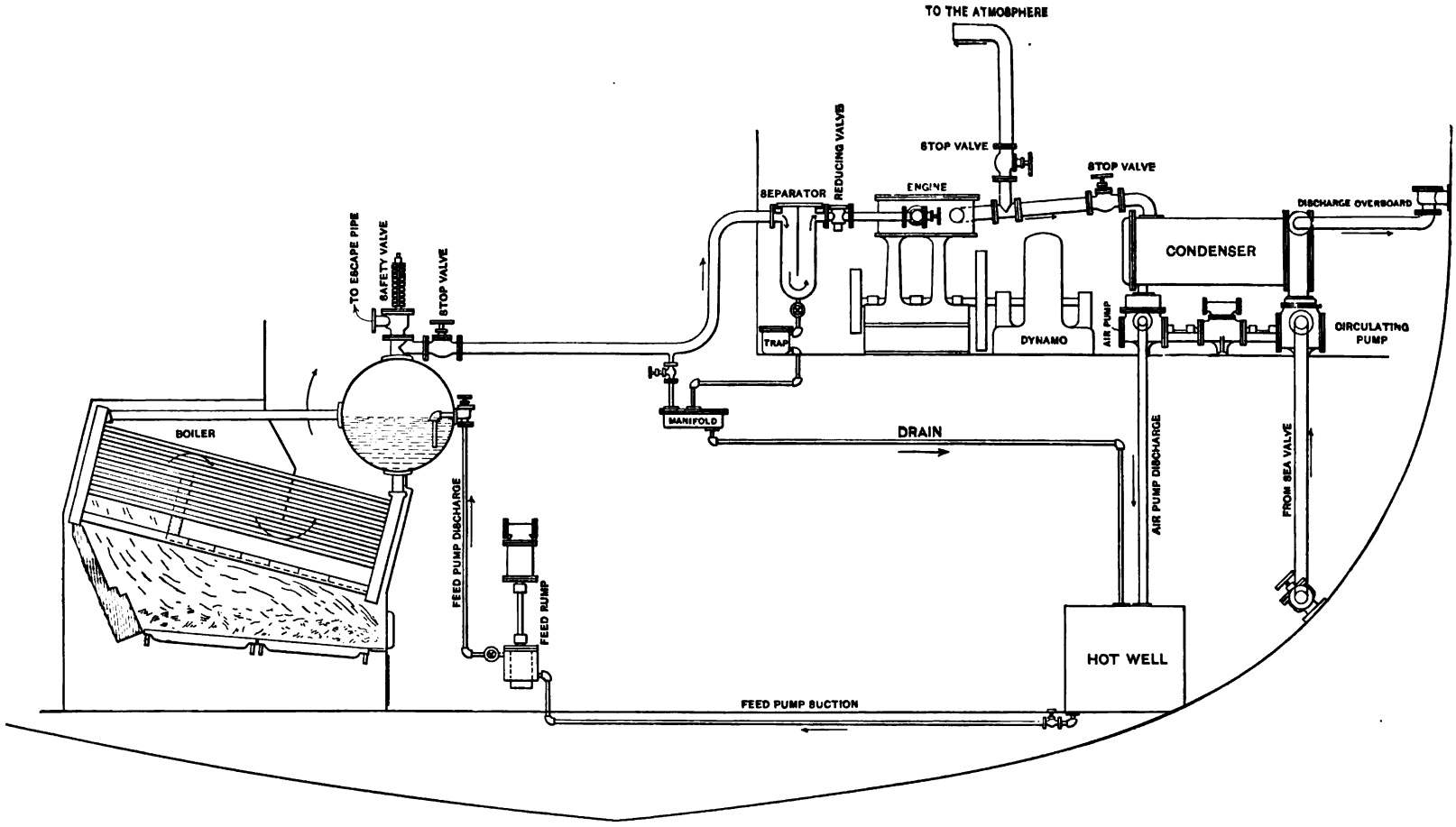

TO THE ATMOSPHERE
STOP VALVE
STOP VALVE
REDUCING VALVE
SEPARATOR
ENGINE
DISCHARGE OVERBOARD
CONDENSER
TO ESCAPE PIPE
SAFETY VALVE
STOP VALVE
TRAP
DYNAMO
AIR PUMP
CIRCULATING PUMP
MANIFOLD
DRAIN
BOILER
FEED PUMP DISCHARGE
FEED PUMP
AIR PUMP DISCHARGE
FROM SEA VALVE
HOT WELL
FEED PUMP SUCTION

PLATE I.

Early Types of Engines.

The first generators installed on shipboard were driven by belts from horizontal engines, but the disadvantages of belt driving were so very evident that it was only tried on one or two vessels. Since then, the generating sets have been directly driven; that is, the power of the engine is directly conveyed to the generator shaft, either by means of a common shaft for engine and generator or by independent shafts connected directly by clutch bearings.

The first few directly-connected engines were horizontal, direct-acting, these being used with the generator known as the Marine Dynamo, which combination did not long find favor.

Following these was the adoption of the general design of engine which was the standard for several years, and which may still be found in service. This type was *simple, single-acting, vertical, inverted, two-cylinder.* The valves were of the piston type, and the arrangement of valves and cylinders in reference to each other and to the governor constituted the differences between the various designs of this same type.

Engine Specifications.

Steam engines for generator driving are built under specifications prepared by the Bureau of Equipment, Navy Department, and those in force at present are as follows:

1. Engines are to be of the automatic cut-off vertical inclosed type, designed to run condensing with maximum practical efficiency at all loads, but capable of satisfactory operation when running noncondensing, to be of sufficient indicated horsepower to drive the generator for an extended time at the rated speed, when said generator is carrying a one-third overload.

2. Sizes 2½ K. W., 5 K. W. and 8 K. W., to be simple engine, single or twin cylinder at the option of the contractor. Sizes of 16 K. W. and above to be cross-compound with cranks set at 180°.

3. The normal steam pressure under which the engine, running condensing with 25-inch vacuum, for different size sets, is to operate, and the maximum allowable water consumption per K.-W. hour output of the set are:

K. W.	Normal steam. pressure.	Water consumption per K.-W. hour, full load.
2.5	100	105
5	100	90
8	100	70
16	100	44
24	100	41
32	100	39
50	150	35
100	150	31

Water consumption to be based on running without lubrication in the steam spaces. A lubricant may, however, be used in the steam spaces, prior to delivery for the test, when surfacing the bearings in the steam spaces.

In testing, corrections shall be made by calorimeter for entrained moisture. Superheating shall not be used in the test.

4. Engines to run smoothly and furnish the required power for full load at any steam pressure within 20% (above or below) of those given in the table, and exhausting to condenser at 25 inches of vacuum; to furnish power for 90% of full load at steam pressure 20% below normal, and for full load at any steam pressure between normal and 20% above normal, when exhausting into the atmosphere.

5. To be so designed that the work done by each cylinder, as shown by indicator cards, will be as nearly equal as practicable under all conditions of load. Indicator motions must be provided which will accurately reproduce the motion of the pistons at all points of the stroke. This will require, for cross-compound engines, the operation of the reducing motion for each cylinder from the cross-head or other moving part belonging to that cylinder.

6. Indicator piping to be installed in a manner to secure accuracy of indicator cards. Connections to be made at each end of each cylinder, and piped to a three-way cock in order that one indicator may be used for both head and crank ends of cylinder. Connections are to fit the standard indicators of the Bureau of Equipment.

7. The length of stroke of the engine to be not less than the diameter of the bore of the high-pressure cylinder.

8. The cylinders to be made of hard, close-grained charcoal iron, bored and planed true, steam and exhaust ports to be short, of ample area and free from fins, scales, sand, etc. Cylinders for sizes 50 K. W. and 100 K. W. will be fitted with a bushing for each piston and piston valve. Bushings to be securely held in place and of sufficient thickness for operation after reboring to a diameter increased by one-quarter inch. Cylinders to be fitted with the usual drain piping, check valves, cocks,

all drains to end in one outlet. In addition to these drains, relief valves are to be fitted to each end of each cylinder, and both high-pressure and low-pressure valves are to be free to lift from their seats to relieve the cylinder of water.

9. The low-pressure cylinder must be fitted with a flat, balanced slide valve; a piston-valve on the low-pressure cylinder will not be accepted.

10. The pistons to be of cast iron or steel, strongly ribbed, light and rigid, and fitted with self-adjusting phosphor-bronze rings, with diagonal lap, each piston to have two or more rings. Rings to override counterbore of cylinders, to prevent wear to a shoulder. The piston and rod to run true at all speeds and to be fitted with such guides or tail rods as are necessary to prevent injurious vibrations.

11. Piston-rods to be of forged steel securely fastened to piston and cross-heads. Cross-heads to be of steel with adjustable shoes. Connecting rods to be of steel with removable babbitt-lined or bronze boxes for crank-pins and bronze boxes for cross-head pins.

12. The crank-shaft to be forged in one piece; counterweights for balancing reciprocating parts to be forged with it or securely fastened thereto. Valve-rods, eccentric rods, and rocker shafts, as well as all finished bolts, nuts, etc., to be of best forged steel.

13. Lagging shall be fitted as extensively as practicable to cylinders, receivers, and steam chests. This shall be done after a preliminary run of the engine in order that any defects in castings or joints may be readily found. The arrangement for securing the lagging in place shall admit of its ready removal, repair or replacement.

14. The steam and exhaust outlets shall be so placed as to admit of piping from either side with equal facility. Blank flanges shall be furnished complete when required to cover alternative outlets.

All flanges for steam and exhaust to be in accordance with Bureau of Steam Engineering standards.

All exhaust flanges will be for copper pipes with composition flanges.

Unless otherwise directed, flanges for steam pipes two inches in diameter and larger will be for steel pipes with steel flanges, and flanges for pipes less than two inches in diameter will be for copper pipes with composition flanges, except when steam is superheated, in which case flanges for all steam pipes will be for steel pipes with steel flanges.

15. Throttle and exhaust valves to be furnished with each set and to conform in every respect to standard specifications and drawings of the Bureau of Steam Engineering. To be 90° angle valves, looking up, unless otherwise specified. Handwheels to be marked, indicating direction of turning for opening and closing. All throttle valves three inches and larger shall be fitted with by-pass valves for warming up cylinders.

16. The governor shall be of the inertia type, arranged to operate the valve by varying the valve travel and point of cut off; must regulate the speed of the engine automatically with throttle wide open within the limits prescribed, and no dashpots or friction washers shall be used in its construction.

17. The speed variation must not exceed 2½% when load is varied between full load to 20% of full load, gradually or in one step, engine running with normal steam pressure and vacuum. A variation of not more than 3½% will be allowed when full load is suddenly thrown on or off the generator, with constant steam pressure, either normal or 20% above normal; a variation of not more than 3½% will be allowed when 90% of full load is suddenly thrown on or off the generator with constant pressure at 20% below normal; exhaust in both cases to be either into condenser or atmosphere. No adjustment of the governor or throttle-valve during the test shall be necessary to insure proper performance under any of the above conditions.

18. The engine column to be designed to inclose all moving parts as far as practicable, or where weight may be saved, by using a wrought-steel frame with an enveloping inclosure of metal. The design of the column shall be such that it is not necessary to raise cylinder for disassembling set. Detachable hinged doors to be provided for examining moving parts while in operation. The design to eliminate all chance of oil or water leaking or being forced through.

19. Stuffing boxes for piston and valve rods to be fitted with self-adjusting metallic packing, except the auxiliary or wiper stuffing boxes in the guard plate, which will be fitted with soft packing, having a lateral bearing surface of length at least equal to the diameter of the rod. If desired, bushings may be fitted in guard plate in lieu of auxiliary or wiper stuffing boxes. Stuffing boxes for piston rods and valve rods to be accessible from the outside of the inclosing case of the engine.

20. A guard plate to be provided to prevent oil from being thrown against the lower cylinder heads and valve chests. Guard plate to be flanged at outer edge and to contain an oil well, with strainer, pipe and valve, for draining water to bilge. The cylinders are to be of sufficient height above the guard plate to insure that no part of piston rods or valve rods which enter the auxiliary or wiper stuffing boxes or bushings in the guard plate will raise to within one-half inch of the lower face of the glands of main stuffing boxes.

21. Engines are required to operate satisfactorily without the use of lubricants in the steam spaces, and this will be demonstrated by a forty-eight hour test for each type and size of engine. The lubrication for all other working surfaces shall be of the most complete character. No part shall depend on squirt-can lubrication.

22. Forced lubrication shall be used wherever practicable, which includes engine shaft, crank-pins, cross-head bearings, eccentric, etc. The engine shall be capable of satisfactory operation with a low grade of lubricating oil, and the forced lubrication shall not be a necessary factor in its cool and satisfactory running. The intent of the forced lubrication is to reduce friction, noise, and attention required.

The pressure for such forced lubrication shall be approximately 15 pounds per square inch, and shall be between 10 and 20 pounds under all service conditions. An oil gauge will be fitted on the front of the set. The main oil-supply pipe to be tapped by a small pipe terminating in a petcock outside of casing. The system to be fitted with a relief valve discharging into column of engine. When it is difficult to determine whether or not oil is feeding properly, a sight oil cup or other suitable device will be installed.

23. The bed-plate is to contain a reservoir and cooling chamber of ample capacity, to be provided with a strainer which may be removed without interrupting the oil supply. The pump to be direct driven by a crank or eccentric on the engine shaft, construction to be simple and durable, and to include a proper guide or support for the plunger rod. The pump to handle clean oil only, not drawing from the top or bottom of reservoir.

To allow inspection while running, the engine crank is not to dip in oil in reservoir.

24. Fly-wheel to be turned on face and sides, inner edge to be flanged to retain any oil which may drip thereon. Hub to be split and clamped to shaft by through bolts. A steel starting bar or its equivalent to be furnished in sizes of 16 K. W. and over, the fly-wheel surface to have not less than six holes for starting-bar.

A starting-bar and set of wrenches and lifting eyes to be furnished and to be suitably mounted in tool board. Stowage to be such that parts will be securely held in place, yet readily removed and returned. When more than one generating set is supplied for one dynamo room, the number of tool boards will be as specified.

25. Mandrels, with collars, complete, shall be furnished for renewing white metal of all bearings so fitted.

26. Metal name-plate to be fitted to engine in a conspicuous place, marked as follows:

MADE FOR
BUREAU OF EQUIPMENT
BY
(*Name of maker here.*)
REQ. NO. ——, 190—,
TYPE ——. CLASS ——. FORM ——.
K. W. ——. STEAM ——. REV. ——.
BORE, ——. STROKE, ——. ROD DIAM., ——.

Engines have been designed and constructed to meet the above specifications or others in force at the time by the General Electric Company, W. D. Forbes & Co., and The B. F. Sturtevant Company. In ships built by the Union Iron Works, there have usually been installed engines built by the same firm. As all are built under the same specifications, they all present the same general characteristics, differing in such details that are not specified, as the kinds of packing, style of governor, etc. By far the greatest number of engines in use have been furnished by the General Electric Company, and only those will be considered in any detail.

Tandem-Compound Type.

This type of engine, made by the General Electric Company, is used with generators of 16, 24, 32 and 50 kilowatts. A cross-section of this engine is shown in Fig. 227.

This design of engine seems to have met every requirement and has proven its worth after ten or more years of experience; the only objection being in the head room required, and which has necessitated the later design of the cross-compound type.

This type of engine gets its name from the two cylinders being in line; the power developed in the cylinders is transmitted to the crank-shaft by a single piston-rod which carries both pistons. The high-pressure cylinder is the lower and over it is secured the low-pressure cylinder. In the engine of the 32-kilowatt size these are respectively 9 inches and 15 inches in diameter with a 6-inch stroke.

The **steam valves** are cast-iron balanced valves. The high-pressure valve receives its motion from the governor through a rocker arm and the low pressure from an eccentric on the shaft. Steam is admitted through the throttle valve to the *inside* of the high-pressure valve *B;* the admission edges marked *FF* control the time of admission of steam to the high-pressure cylinder, and the exhaust edges *GG* control the time of the exhaust from the high-pressure cylinder to the receiver *D*. After the steam has done its work on the high-pressure piston and is exhausted into the receiver *D,* it enters the body of the low-pressure valve *A* which controls the ad-

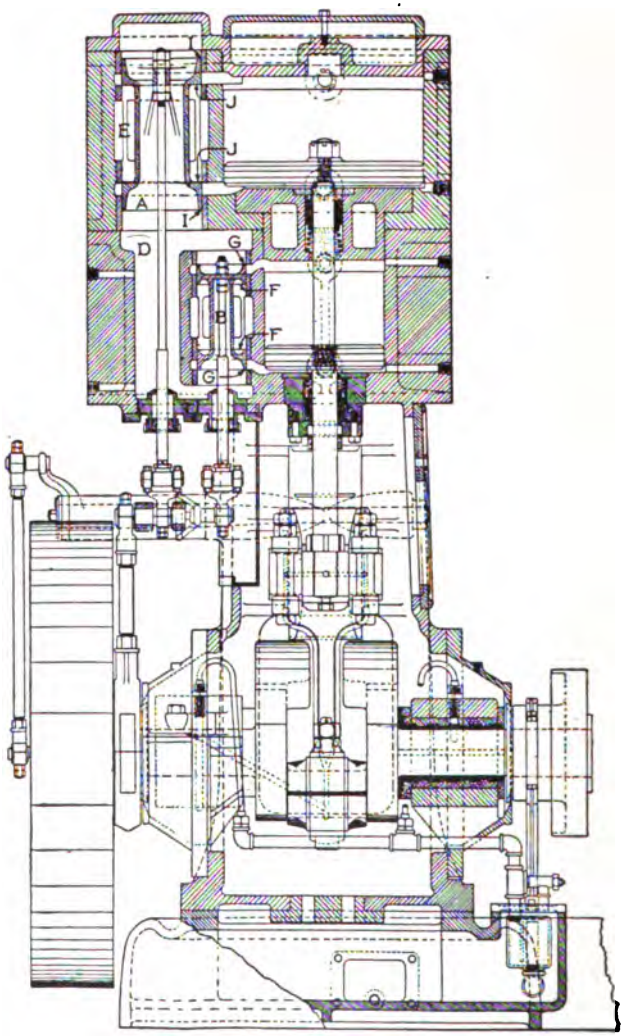


FIG. 227.—Cross-Section Tandem Compound.

mission of steam to the low-pressure cylinder by the edges *II* and the exhaust by the edges *JJ*. After the second stage of expansion in the low-pressure cylinder the steam is finally exhausted into *E*.

The travel of the high-pressure valve is controlled by the governor and varies between 3 inches and $1\frac{3}{8}$ inches and the cut-off varies between $\frac{3}{4}$ and zero, depending on the load. The cut-off in the low-pressure valve is fixed at $\frac{5}{8}$ stroke, while the valve has a fixed stroke of $3\frac{1}{16}$ inches. The steam lap of the high-pressure valve is $\frac{3}{4}$ inch, the exhaust lap, top and bottom is 0 inch. The steam lap of the low-pressure valve is $\frac{1}{16}$ inch, the exhaust lap is top 0 inch, bottom $\frac{1}{16}$ inch.

Valve Stems.—Both valves turn freely on the stems without play. The lower ends of the stems are threaded and screw into a small cross-head to which they are secured by lock-nuts. The central portion of this cross-head is square while the ends are cylindrical forming bearings by which the cross-head is connected to the link. The caps of the bearing are secured by bolts screwed into the bottom of the link bearing surface and locked by a nut. Wear in the bearing caps is taken up by filing the face of the caps.

Pistons.—The low-pressure piston is of cast iron with a single rectangular groove which receives the piston packing. The piston is screwed on the rod against a taper shoulder and is secured by a lock nut in the face of which are radial grooves. A split pin passes through the end of the rod and lies in one of the grooves.

The high-pressure piston is of steel and is screwed to the rod and riveted to prevent unscrewing.

The **piston-rod** is of forged mild steel, and for the 32-kilowatt size is $1\frac{5}{8}$ inches in diameter for the low-pressure section and $1\frac{1}{8}$ inches for the high. It is threaded at the lower end for screwing into the cross-head, where it is locked by a spanner jam nut.

The **piston packing** consists of four cast-iron arcs, overlapping at the ends and made steam-tight by brass tongues, one of which is riveted to each arc. The packing is held against the cylinder by flat steel springs, one to each arc. The packing for the high-pressure piston is the same with the exception of three instead of four parts.

Piston-Rod Packings.—There are known as the "Single-Junior" type and are shown in Fig. 228.

Three rings of babbitt metal packing rest on a vibrating cap which has a spherical bearing. Over the metallic packing and around the rod is a sleeve pressed by a coiled spring. Steam pressure forces the packing against the rod and the spring prevents the packing from following the rod on reversal.

The cover for the metallic packing in the high-pressure cylinder forms a second stuffing-box for two rings of soft packing, which is

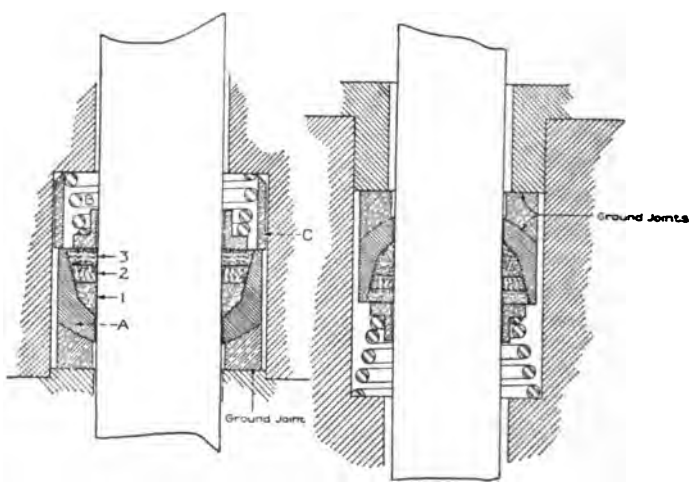


FIG. 228.—Single-Junior Piston-Rod Packings.

used to prevent water from following the rod and mixing with the oil.

The **connecting rod** consists of a forged steel body forked at the upper end for receiving the wrist-pin brasses. Wear is taken up by filing the faces of the brasses. The crank-pin bearing consists of a cylindrical cast-steel shell in halves. The interior of the shell is babbitted where it bears on the crank-shaft, and wear is taken up by removing liners between the halves of the steel shell. The bearing boxes should be kept tight to prevent leakage of oil which is forced from this bearing to the cross-head guide.

The **crank-shaft** with the crank is made from one solid piece of forged steel. Cast-iron balance weights are secured on the cranks opposite the crank-pin.

In the coupling between the engine and generator shaft are four 1-inch bolts, with two $\frac{5}{8}$-inch set-screws for separating the two parts when the armature is disconnected.

The **main bearings** are two in number and are cast-iron cylindrical shells, 8 inches in length. The shells are in two parts; the lower part receives the main bearing boxes and the upper part acts as a cover to prevent the throwing of oil. The bearing boxes are of cast iron lined with a babbitt metal with a facing next the crank of the same material. Wear is taken up by machining off the composition liners between the boxes.

The **governor** is on the shaft on the end farthest from the generator and is contained in a heavy fly-wheel made very large and heavy which is keyed to the shaft. The governing mechanism contains a single fly-weight connected to the lever carrying the pin that operates the high-pressure valve. A circular coiled spring opposes the motion of the fly-weight and by increasing or decreasing the tension of this spring the speed may be varied. Increasing the tension of the spring decreases the tendency of the fly-weight to move out and the travel of the valve is less readily influenced and the effect is to increase the speed. The same effect can be produced by moving the spring in the slot away from the fulcrum, as this has a tendency to increase the tension and consequently the effect is to increase the speed.

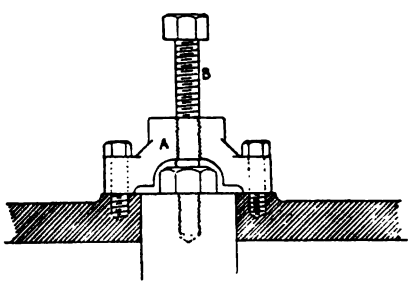


FIG. 229.

To Remove Governor Wheel.—The governor wheel must be taken off before the crank-shaft can be removed. This is accomplished by means of the governor disconnector furnished with the engine tools.

Fig. 229 shows the disconnector in place for removing the gover-

nor wheel. It is bolted to the wheel on each side of the shaft. A nut with recessed head is screwed into the crank end, and the bolt *B* is screwed down through the connector on this nut, thus raising the connector on the bolt and the latter withdrawing the wheel.

Fig. 230 shows the disconnector in place for replacing the governor wheel. There is a square-headed nut screwed into the end of the crank-shaft, and on this bears the bolt *C*, screwing through the disconnector *A* and being set down by turning the nut *E*. *A* is bolted to the wheel as before, and screwing down *E*, forces *A* down, forcing the wheel on the shaft.

Lubrication.—Engines of the tandem type employ the forced system of lubrication. The general system adopted is illustrated in Fig. 231. The base of the engine forms an oil tank to which is attached a small plunger pump driven by an eccentric on the shaft. The lubricant is carried under pressure to the various parts of the engine by the mechanism shown in the figure.

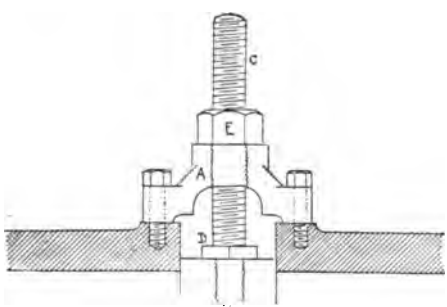


FIG. 230.

The oil is forced by a pump to a groove in the main bearing, and a drilled hole in the shaft connects this groove with the crank-pin. From the crank-pin box the oil is further forced to the wrist pin through the pipe running along the side of the connecting rod. The passage in the cross-head allows the oil to be forced from the wrist pin to the guides.

As the oil is forced from one bearing to another, it is quite important that the bearing caps be set tight, otherwise the oil will escape before reaching the last bearing. After passing through the bearings the oil is collected in the base, strained and used again.

This system of lubrication is perfectly reliable, prevents hot bearings, and reduces the wear to a minimum with the least attention. It is important that the oil be free from all substances, such

as particles of waste or grit, and to guard against the introduction of any foreign matter, a strainer which may be taken out for examination or cleaning, is attached to the suction valve of the pump. An oil pressure of from 5 to 20 pounds should be maintained, and may be regulated by adjusting the set-screw on the relief valve of the oiling system. The pressure gauge need not remain in the circuit continuously. Only mineral oils should be

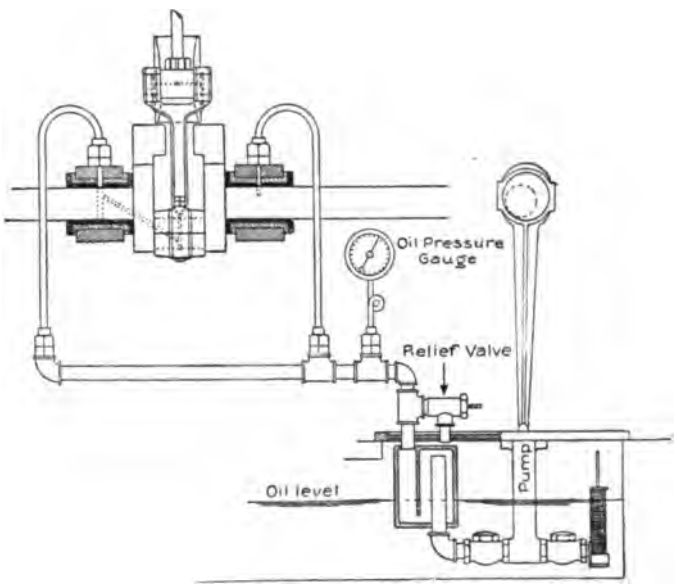


FIG. 231.—Lubricating Mechanism.

used for lubrication. A heavy oil gives better results and prevents knocking more effectively than thin oil. An oil which has been found to give good results consists of two-thirds red engine oil and one-third heavy cylinder oil. As the oil passes through the bearing repeatedly, it gradually loses its lubricating properties, becoming thick and gritty, and should be occasionally run through a filter and mixed with new oil. The frequency of this change depends upon the oil, as well as the number of hours the engine is in operation, and can be easily determined by observation. The

oil in the reservoir should stand about 2 inches over the suction and discharge valves, and no water should be allowed to mix with it. Should any water accumulate in the base it should be drawn off by the cock provided for the purpose before starting the engine.

General Electric Form H-1 Engine.

This form of engine, made by the General Electric Company for use with their generators, followed the type of the tandem compound, and was designed to meet the specification calling for a *cross-compound* engine, which became a necessity on account of the head room of the larger sizes of the tandem type.

The following description of the various parts is taken from the Instruction Book furnished by the makers, and for an engine to drive an MP-6-24-400-80 generator:

Engine.—The engine is of the vertical, cross-compound, double-acting, enclosed type, with cranks 180° apart, and has a speed of 400 revolutions per minute at full load, with 100 pounds steam pressure and 25-inch vacuum exhaust.

Part of the heavy base supporting the engine and generator forms a reservoir for the oil used in lubricating the moving parts of the engine. This chamber is also utilized as a settling and cooling chamber. The base is provided with a depression around the engine column for the collection of waste oil and drippings, and is provided with a stopcock for drainage.

On the back of the engine base is cast a boss to which is attached a sight tube oil gauge, for indicating the height of oil in the reservoir.

The crank pit, which is enclosed by the column and base, is accessible through doors in the front and back of the engine.

Steam Pressure.—The range of steam pressure for this engine is between 80 and 120 pounds, with a normal pressure of 100 pounds and 25-inch vacuum. The engine will carry an overload of 33⅓ per cent without trouble. It is advisable to maintain normal steam pressure, if possible.

Cylinders.—The cylinders are $6\frac{1}{2}'' \times 10\frac{1}{2}''$ with a stroke of 7 inches. The high-pressure and low-pressure cylinders, with their respective steam chests, are a single casting of hard, close-grained

cast iron, accurately bored and externally covered with a thick layer of best quality asbestos, and is lagged with planished sheet

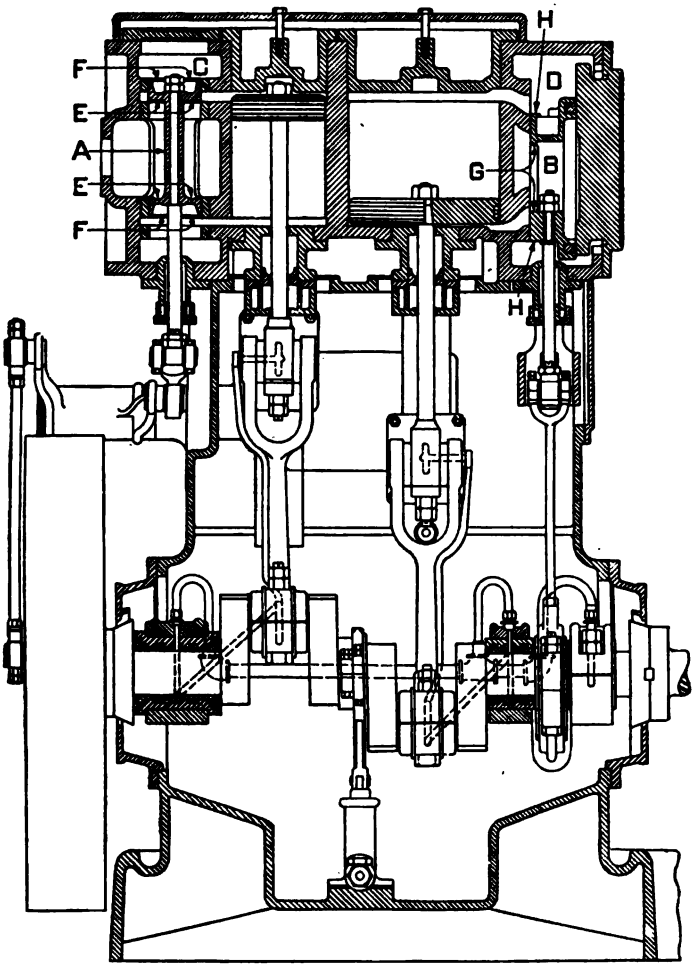


FIG. 232.—Vertical Section of Engine. Form H-1. Gen. Elec. Co.

iron. The receiver, of proper dimensions, forming a part of the cylinder casting, conveys the exhaust steam from the high-pressure

cylinder to the low-pressure steam chest and is tapped for a ½-inch drain pipe. For ease in casting, an opening is formed in the receiver, this opening being closed by a cover secured by eight ⅝-inch studs and nuts. Both cylinders have relief valves and are tapped for drain and indicator valves. The draining arrangement with ½-inch relief valves and three-way cock for high-pressure cylinder, is shown in Fig. 233. The ¾-inch relief valves for the low-pressure cylinders are of the same construction. The high-pressure steam chest cover, the low-pressure cover with relief plate, and high-pressure and low-pressure cylinder heads are shown in Fig. 232.

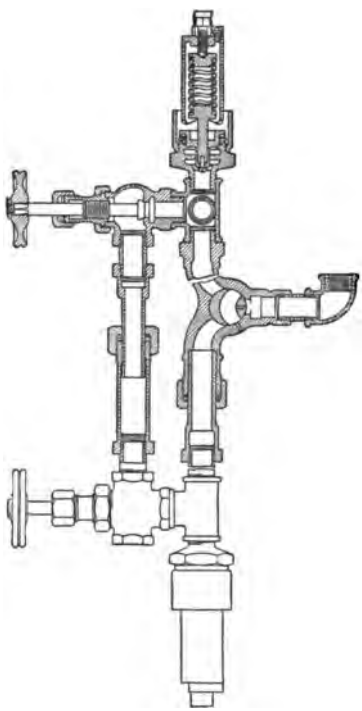


FIG. 233.—Draining Arrangement.

The high-pressure cylinder head is fastened to the cylinder by seven ⅝-inch studs and the low-pressure cylinder head by eight ⅝-inch studs. The flanges of both heads and low-pressure steam chest cover are tapped for two ⅝-inch eyebolts for use in lifting these parts.

The high-pressure steam chest cover and high and low-pressure cylinder heads are covered by a polished cast-iron hood.

Steam Distribution and Valves.—The steam distribution is accomplished through one cast-iron balanced piston-valve *A* (Fig. 232) and one flat, partially balanced slide-valve fitted with relief ring to reduce friction, and driven by an eccentric fixed on the crank-shaft, and, therefore, always gives the same cut-off. The inner face of the low-pressure steam chest cover is exactly parallel with the valve seat and upon this surface the circular ring of the low-pressure valve has its bearing. This ring fits a groove in

the valve and is held in place by springs and is self-adjusting for steam tightness, thus automatically following up all wear and affords necessary relief in case of water in the cylinder.

Timed by the movement of valve *A*, the steam enters the high-pressure cylinder chest and valve in proper quantities through the throttle-valve, and after doing its work in the high-pressure cylinder, is exhausted in receiver *C*, admitted to the low-pressure cylinder by valve *B*, and finally exhausted through passage *D*.

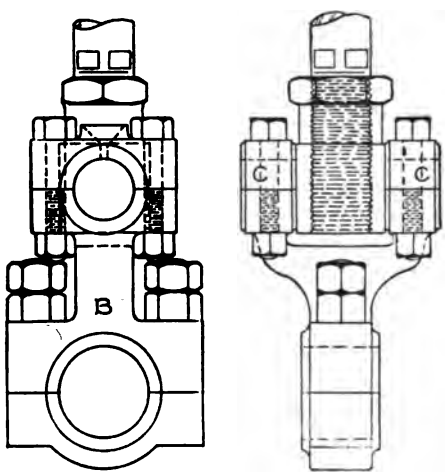


FIG. 234.—Cross-Head and Link.

High-Pressure Valve.—The high-pressure valve takes steam on the inside, the admission edges being at *E* and *E*, and the exhaust edges at *F* and *F*.

The steam lap is $\frac{81}{64}$ inch; the exhaust lap top and bottom is 0 inch. The travel of this valve is controlled by the automatic governor, and varies between $2\frac{1}{2}$ inches and $\frac{1}{8}$ inch. The cut-off varies between $\frac{3}{4}$ and 0, depending upon the load.

Low-Pressure Valve.—The admission edges of the low-pressure valve are at *G* and *G*, and the exhaust edges at *H* and *H*.

The steam lap is $1\frac{3}{16}$ inch, and the travel of the valve $2\frac{3}{4}$ inches, giving a cut-off of about 0.58 stroke. The exhaust lap is minus $\frac{1}{16}$ inch top and bottom.

Valve Stems.—The upper ends of the valve stems pass through the valves, the valves being secured by double $\frac{5}{8}$-inch nuts on their upper sides and by shoulders turned upon the valve stems on their lower sides. In addition, the low-pressure valve stem is fitted with a washer fitted to a taper on the stem which allows the valve to properly adjust itself on the stem.

The nuts should be locked hard together, but the stems should be free to turn in the valves, though without any play.

The valve stems are threaded at their lower ends, and screw into small cross-heads, to which they are secured by lock-nuts. The central portions of these cross-heads are square, with their ends cylindrical, the high-pressure valve stem cross-head forming a bearing with link *B* (Fig. 234). The bearing caps *C* and *C* for the

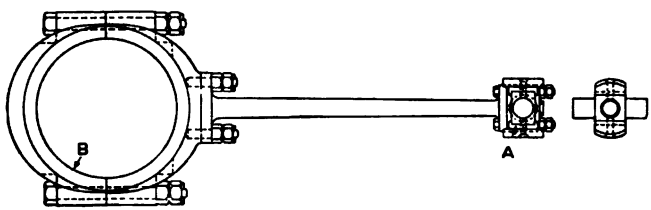


FIG. 235.—Eccentric Rod and Strap.

valve-stem cross-head are each secured by bolts. The lower end of the link of the high-pressure stem contains a bearing similar in construction, which receives a fixed pin in the rocker arm. The wear is taken up by filing the cap faces. The low-pressure valve stem cross-head forms a bearing with brasses secured to the forked ends of the eccentric rod. In the square section of this cross-head are drilled and tapped, at right angles to the hole receiving the valve stem, two holes for receiving the $\frac{1}{4}$-inch flat-headed screws which secure the two bearing-metal shoes to the cross-head, having a bearing in the cast-iron guide bolted to the cylinder, which acts as a guide for the valve stem.

Lost motion may be taken up by inserting thin liners between the cross-head body and the shoes.

The guide is shown in Fig. 232, while the cross-head and shoes are shown in Fig. 235.

Valve-Stem Stuffing-Box.—Fig. 232 shows the valve chest bonnet with stuffing-box. Ordinary soft packing of good quality may be used in this stuffing-box.

Low-Pressure Eccentric Rod and Strap.—The low-pressure eccentric rod and strap complete are shown in Fig. 235. The upper end of the eccentric rod is forked and receives the brasses of the low-pressure valve stem cross-head, its lower end being secured to the top half of the strap by two ½-inch studs.

Wear is taken up by filing the bearing faces of *A* and *B*.

The lubrication for the eccentric strap is accomplished by oil holes drilled through the eccentric, which communicates with the inside of the engine.

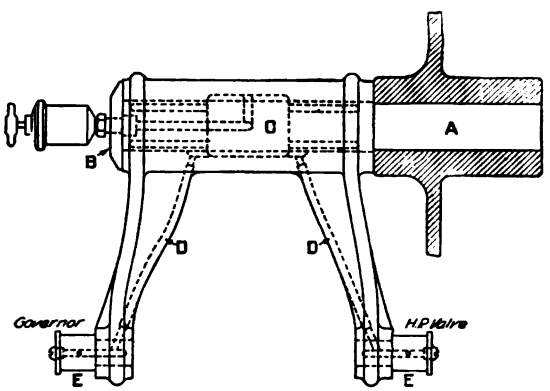


FIG. 236.—Rocker Arm.

Rocker Arm.—The motion for the high-pressure valve is transmitted from the governor through the rocker arm, bearing upon stud *A* (Fig. 236), which passes through the engine column. The washer *B*, at the end of the stud *A*, is tapped for a screw grease cup which forces the lubricant to chamber *C*, in the rocker arm. The grease is further pressed from this chamber through pipes *D* and *D* to pins *E* and *E*.

Governor.—The governor is illustrated in Fig. 237, and consists of a heavy fly-wheel *A*, keyed to the shaft and carrying the governor parts, the latter consisting of a single fly-weight *B* pivoted at *C* and containing the eccentric pin *D* which operates the high-pressure valve.

The operation of the governor is as follows:

The governor connecting rod (Fig. 238) which transmits motion from the governor to the high-pressure valve is connected to eccentric pin *D*. It is therefore evident that the length of the valve stroke depends upon the distance of *D* from the center of *E*. The amount of steam admitted to the cylinder varies directly as the distance between the centers of *D* and *E;* that is, the less the distance the less the amount of steam admitted, and vice versa.

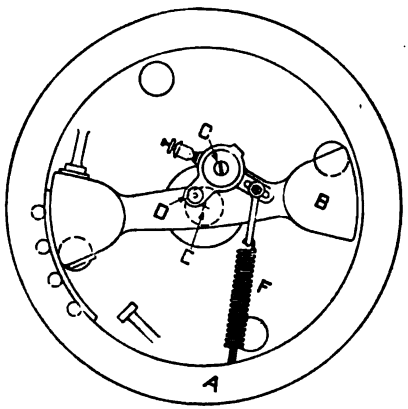


FIG. 237.—Governor.

Suppose the speed of the engine to increase; the weight *B* is immediately drawn out by centrifugal force toward the perimeter *A*, thus decreasing the distance of *D* from the center of *E* and reducing the amount of steam admitted to the cylinder. Should the speed of the engine approach a dangerous point, the distance of *D* from the center of *E* will be diminished until the minimum distance is reached, when the steam is entirely cut off from the cylinder. The motion of the fly-weight is opposed by the spring *F*, which is attached to the pulley and fly-weight. By increasing or decreasing the tension of the spring, the speed may be raised or lowered. The same effect will be produced by moving the spring in the slot of the weight—moving it away from the fulcrum increases the speed, and toward the center produces the opposite effect. Unstable regulation may be due to one of two causes—insufficient lubrication of the fly-weight fulcrum, or too close an adjustment of speed. The former may be avoided by occasionally cleaning the governor; the latter by moving the spring attachment away from the fulcrum. Only the best quality of soft grease should be used in the cup.

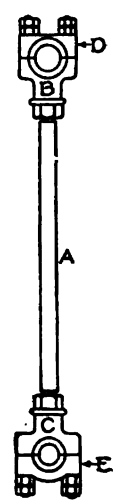


FIG. 238 Governor Connecting Rod.

Method of Handling Governor Wheel.—The removal of the governor wheel is accomplished by the use of the governor disconnecter shown in Figs. 229 and 230.

Governor Connecting Rod.—The governor connecting rod complete is shown in Fig. 238. The body *A* is threaded and screwed into the top and bottom of bearing metal boxes *B* and *C*, and secured by lock-nuts. The bearing caps *D* and *E* are each secured by two ⅜-inch studs with double nuts.

Wear is taken up by filing the bearing faces of caps *D* and *E*.

The lubrication of the top box is through the rocker arm as described under the heading "Rocker Arm" and for the bottom box through valve motion lever in the governor.

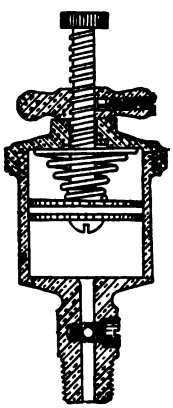


FIG. 239.

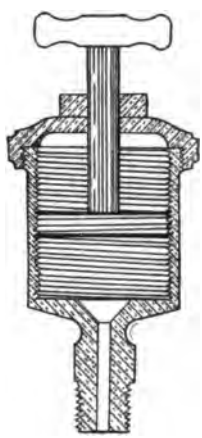


FIG. 240.

Grease Cups.

Grease Cups.—The different types of grease cups used on this engine are shown in Figs. 239 and 240. Fig. 239 shows the automatic type "Ideal No. 1." The cup is provided with a leather-packed plunger, against which rests a coiled spring. The spring and the plunger are conveniently controlled by a thumb nut; turn this to the right until the plunger is raised to the top of the cup, unscrew the cover and fill the cup with grease. Replace the cover and adjust the pressure on the grease by turning the thumb nut to the top of the stem, allowing the spring to press on the plunger,

forcing out the grease. The rate of speed may be regulated by the set-screw in the lower part of the cup in which there is a hole in line with the slot.

The "Marine" grease cup No. 1 is used for forcing the lubricant to the rocker-arm and valve-motion pins. The operation is easily understood from the sketch.

Indicator Motion.—When it is desired to indicate the engine, a small cover must be removed from the front column door, exposing a slot over which a bracket containing a bearing pin for the lever is attached.

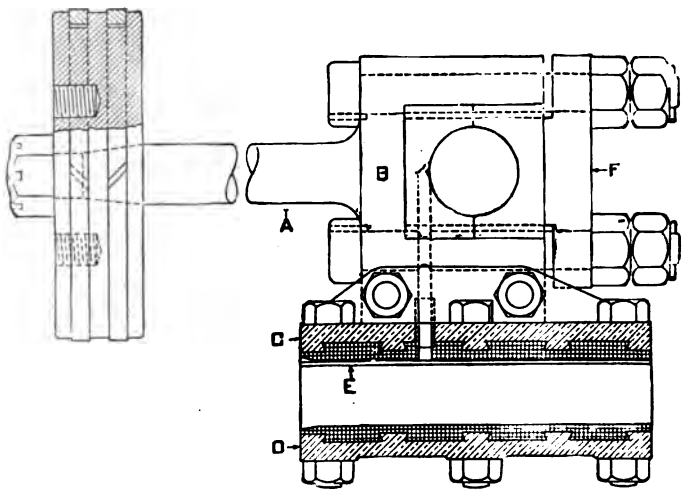


FIG. 241.—Piston, Rod and Cross-Head.

The indicator motion consists of a stud screwed into the wrist pin of the high-pressure connecting rod for driving the motion, which connects through a link to a lever pivoted to the bracket covering the slot in the door. The motion for the indicator is taken from a cord pin on this lever.

Piston, Rod and Cross-Head.—The piston-rod *A* and the cross-head *B* (Fig. 241) are in one forging of mild steel.

The diameter of both high-pressure and low-pressure rods is $1\frac{3}{16}$ inches.

The cross-head shoe *C* is of composition metal, babbitted, and has a very liberal wearing surface so that the wear at this point will be very slight. The cross-head shoe is fastened to the cross-head by two $\frac{5}{8}$-inch bolts and is held against the guide bar by the clamp *D*, which is connected to the shoe by six through bolts. The proper distance between the shoe and clamp is maintained by adjustable liners *E*. The cross-head is slotted to receive the wrist-pin bearing, which is made of gun metal, and is held in place by cap *F* and two bolts with double nuts. Feathers $\frac{1}{8}$ inch in diameter and $\frac{3}{4}$ inch long, projecting through the bolt heads and extending into the body of the cross-head prevent the bolts from turning. The bearing should be so adjusted that when the brasses are hard together the wrist pin will move freely but without any play.

Oil reaches the bearing from the oil pipe *G* (Fig. 243), passing up the side of the connecting rod; from this bearing it is further forced to guide.

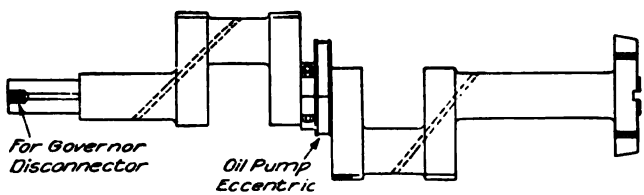


FIG. 242.—Crank-Shaft and Coupling.

Pistons and Piston Packing.—The high-pressure piston is shown in Fig. 241, and is a cast-iron disk containing two rectangular grooves, which receive the piston packing, consisting of a single cast-iron spring ring, overlapping at the ends and forming an angle joint. The piston fits on a taper on the rod and is secured by a nut on the upper side. The outer face of this nut has radial grooves cut in it. A split pin passes through the nut, preventing it from working loose.

The general construction of the low-pressure piston is the same as that for the high pressure.

Crank-Shaft and Coupling.—The crank-shaft and coupling (see Fig. 242) for transmitting the power to the generator are made in one solid piece of forged steel with the crank-pins machined out.

The shaft on one end receives the governor wheel and on the opposite end the coupling has four $\frac{1}{2}$-inch bolts, while two $\frac{5}{8}$-inch set-screws are used for forcing the coupling apart when it is desired to disconnect the armature.

To the face of the coupling is secured by four $\frac{1}{4}$-inch flat-headed screws the radial key $\frac{5}{8}$-inch square for transmitting the power.

The shaft has a diameter of 3 inches at the bearing and $2\frac{3}{4}$ inches at the governor end.

Connection Rod.—The connection rod consists of a forged-steel body *A* (Fig. 243) forked at its upper end for receiving the wrist pin, which is shrunk into the rod. The bottom end of the rod terminates in a stud, to which the crank-pin box is secured by a steel cap *B* and two $\frac{3}{4}$-inch forged steel through bolts *C*, held by lock-nuts D. Split pins pass through the ends of these bolts, preventing the lock-nuts from coming off.

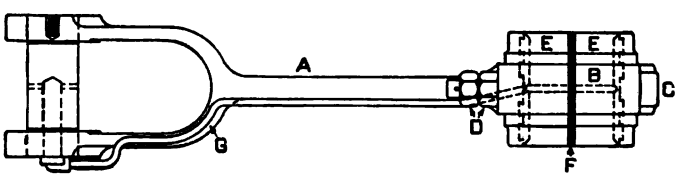


FIG. 243.—Connection Rod.

The crank-pin bearing consists of a hollow, cylindrical, cast-steel shell *EE*, split in halves. The shell has two small flanges which fit the connecting rod and prevent the shell from moving sideways. It is prevented from turning by the through bolts which intersect it and thereby make a guide for it. The interior of the shell, which comes in contact with the shaft, is babbitted and wear may be taken up by removing the fiber liners *F*.

It is important that the boxes should always be tight together in order to prevent the oil from leaking out, as the oil must be forced from this bearing through pipe *G* up to the wrist pin and cross-head guide.

Throttle-Valve.—Fig. 244 illustrates the throttle-valve furnished with each engine. It is of the Lunkenheimer regrinding type and

is 2 inches in diameter. When the valve seat becomes worn and leaky it may be reground in the following manner:

Unscrew the bonnet ring and take the valve apart. Place a little powdered sand and soap on the disk. Insert a nail or a piece of wire in the holes in the disk and stem to prevent the revolving of the disk on the stem, and then regrind the valve. The bonnet ring should be left unscrewed, so that the bonnet will rotate and guide the stem while the valve is being reground. When properly reground, the valve will again be steam-tight.

All other valves used on this engine are of the same make and construction and, therefore, can be reground in the same manner.

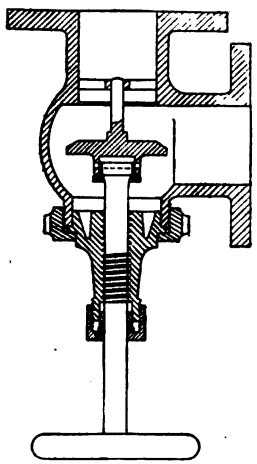


FIG. 244.—Throttle-Valve.

Lubrication.—The lubricant is carried under pressure to the various parts of the engine by the mechanism shown in Fig. 245. The base of the engine forms an oil tank to which is attached a small plunger pump driven by an eccentric on the shaft. The oil is forced by this pump to grooves in the main bearings, and drilled holes in the shaft connect these grooves with the crank-pins, the oil being further forced to the wrist pins through the pipes on the side of the connection rods.

The passages in the cross-heads (see Fig. 241) allow the oil to be forced from the wrist pins to the guides. As the oil is forced from one bearing to another it is quite important that the bearing caps be set tight, otherwise the oil will escape before reaching the last bearing. After passing through the bearings the oil is collected in the base and used over again.

This system of lubricating is perfectly reliable, prevents hot bearings and reduces wear to a minimum, and necessitates the least attention. It is important that the oil be free from all substances such as particles of waste or grit, and to guard against the introduction of any foreign matter a strainer is attached to the suction valve of the pump, which may be taken out for examination or cleaning at any time whether the engine is in operation or not.

A pressure gauge is attached to the system to show the pressure of the oil, but it is not necessary to keep the gauge in circuit continuously.

An oil pressure of from 10 to 20 pounds should be maintained

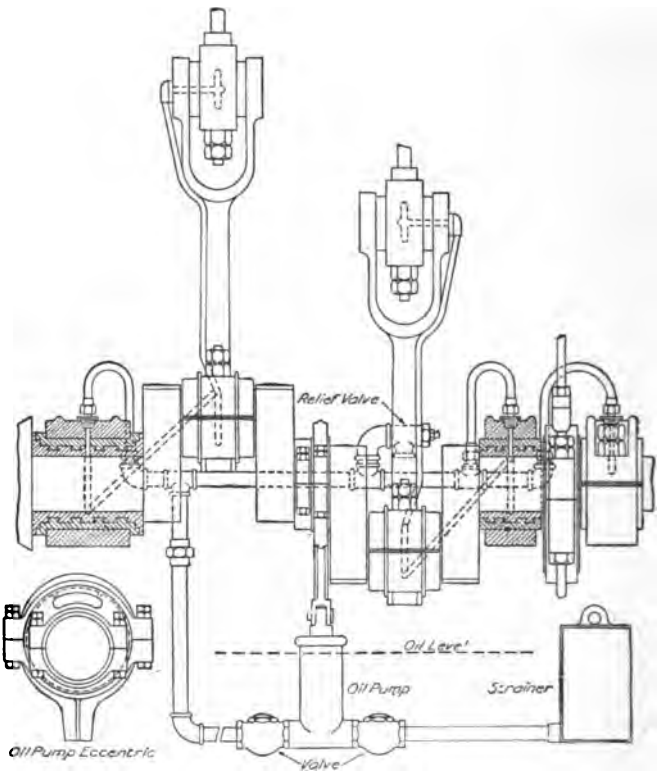


FIG. 245.—**Lubricating Mechanism.**

and may be regulated by adjusting the set-screw of the relief valve projecting through the casing on the back of the engine.

Only mineral oils should be used for lubrication. A heavy oil gives better results and prevents knocking more effectively than thin oil. An oil which has been found to give good results consists of two-thirds red engine oil and one-third heavy cylinder oil. As the oil passes through the bearings repeatedly, it gradually loses its

lubricating properties, becoming thick and gritty, and should be occasionally run through a filter and mixed with new oil.

The frequency of this change depends upon the oil as well as the number of hours the engine is in operation, and can be easily determined by observation.

A small door bolted to the base is utilized when it is found necessary to clean the reservoir, the oil being first drawn off by a drain cock attached to a boss in the front of the engine.

The oil in the reservoir should stand about 2¾ inches over the suction and discharge valves, and no water should be allowed to mix with it.

Starting the Engine.—Before steam is admitted to the cylinders care must be taken to see that the valves move freely. This may be done by turning the governor wheel by hand. As the expansion of the valves is much more rapid than that of the cylinder, the cylinder should be allowed to attain its proper temperature before full pressure is applied.

A small pipe ½ inch in diameter, fitted with a valve, is connected between the receiver and the throttle valve. This is for the purpose of heating the engine before starting. The drain from the receiver, together with all the cylinder drain valves, should be kept open, to allow all condensed water to escape.

If water hammering occurs after the engine is started, it can be stopped by admitting live steam to the receiver and low-pressure cylinder.

Main Bearings.—The main bearings, three in number, are of cast-iron shells split in halves, the lining and facing next to the cranks being of the best grade of babbitt. Wear may be taken up by filing or machining off the brass liners between the boxes. These liners also prevent the boxes from turning. Care should be taken to see that the liners are set close to the shaft so that the oil does not flow out of the ends of the boxes, causing a loss of pressure.

The lower half of the box can be easily removed for repair or examination by slightly raising the shaft.

Over the end bearings are hollow cylindrical cast-iron covers 2½ inches in length with flanges for bolting to the column. Free access to the end bearings may be had by removing these covers.

Piston-Rod Packings.—The piston-rod packing is shown in Fig. 246 and is known as the "Class No. 1" or "Double" type and is used on both the high-pressure and low-pressure rods.

The packings consist of vibrating cups *A* and *A* receiving the packing rings, 1, 2 and 3. These rings are in halves and in assembling the packings care should be taken to see that the joints

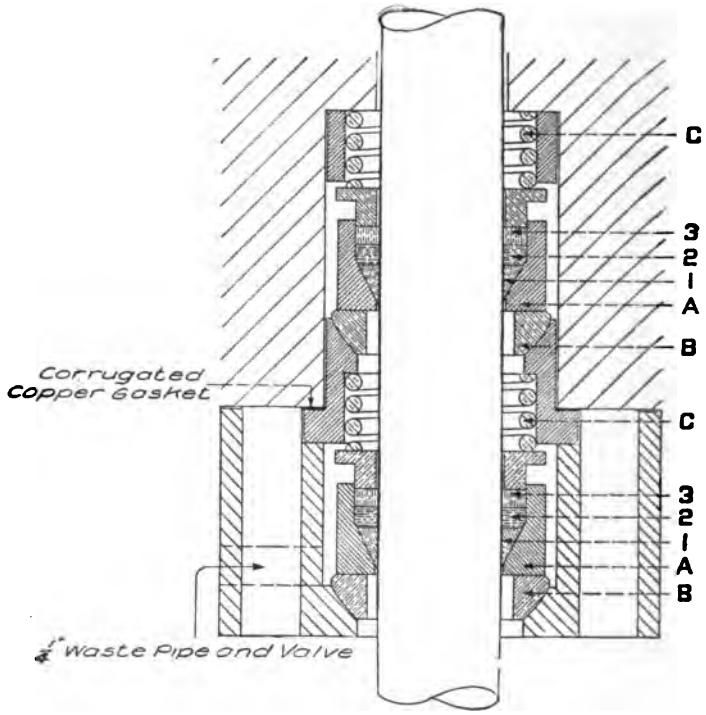


FIG. 246.—Piston-Rod Packing.

are broken. The vibrating cups rest upon rings *B* and *B*, which have a spherical bearing so that the packings will follow the rod in any position. The steam pressure forces the packing down in the cups and against the piston-rod, thereby preventing the leakage of steam. The coil springs *C* and *C* assist this pressure, at the same time holding the packing in place and preventing the rings from

following the rod at the moment of reversal. When the packing has been taken out for examination or other purposes, the ground surfaces should be perfectly clean and free from grit before assembling.

The box holding the packings is drilled and tapped for a $\frac{1}{8}$-inch waste pipe and fitted with a globe valve which should at all times be open.

General Electric Form H-2 Engine.

This form of engine made by the General Electric Company replaced form H-1, and many of this design will be found on our later ships of war. It differs somewhat in its detail from form H-1, the principal difference being in the arrangement of the governor which is removed from the fly-wheel casing and placed inside the engine casing. This form of engine is used with generators up to 100 kilowatts capacity. Its details will only be considered in the differences from form H-1, and all dimensions given are for the engine of the 100-kilowatt generating set.

Steam Pressure.—The range of steam pressure for this engine is between 120 and 180 pounds, with a normal pressure of 150 pounds and 25-inch vacuum. The engine will carry an overload of $33\frac{1}{3}$ per cent without trouble. It is advisable to maintain normal steam pressure, if possible.

Cylinders.—The cylinders are 10 and 18 inches with a stroke of 10 inches. The high-pressure and low-pressure cylinders are separate castings of hard, close-grained cast iron, accurately bored and externally covered with a thick layer of best quality asbestos, and are lagged with planished sheet iron. The high-pressure cylinder and steam chest are in one casting; the low-pressure steam chest is bolted to the low-pressure cylinder.

The receiver, forming a part of the cylinder castings, conveys the exhaust steam from the high-pressure cylinder to the low-pressure steam chest.

Both cylinders have relief valves and are tapped for drain and indicator valves. The draining arrangement with 1-inch relief valve, swinging check valves and three-way indicator cock for high-pressure cylinder, is shown in Fig. 247. The $1\frac{1}{2}$-inch relief valves

for the low-pressure cylinder are of the same general construction. The high-pressure steam chest cover and cylinder head, the low-pressure cylinder head, and the low-pressure steam chest cover and relief plate are shown in Fig. 248.

The high-pressure and low-pressure cylinder heads are each fastened to their respective cylinders by twelve $\frac{7}{8}$-inch studs and

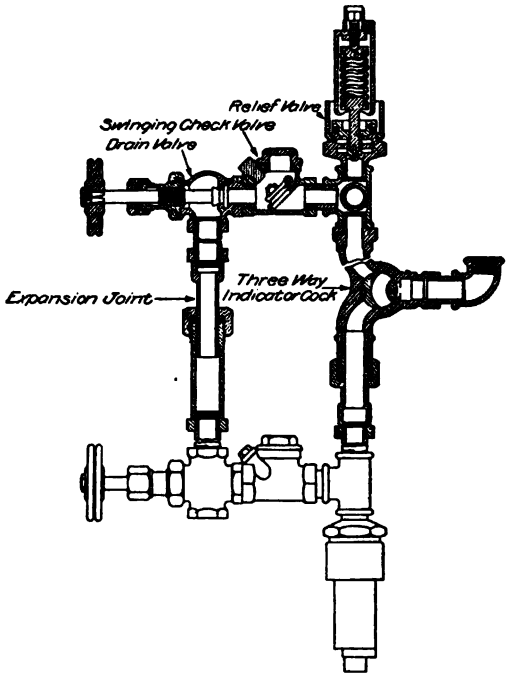


FIG. 247.—Draining Arrangement.

nuts. The flanges of both heads and low-pressure steam chest cover are tapped for two $\frac{3}{4}$-inch eye-bolts for use in lifting these parts.

The high-pressure and low-pressure cylinder heads are covered by polished cast-iron hoods.

Valve-Stem Stuffing-Box.—Fig. 248 shows the valve-chest bonnet with stuffing-boxes. Ordinary soft packing of good quality may be used in these stuffing-boxes.

High-Pressure Valve.—The high-pressure valve takes steam on the inside, the admission edges being at *E*, and the exhaust edges at *F*.

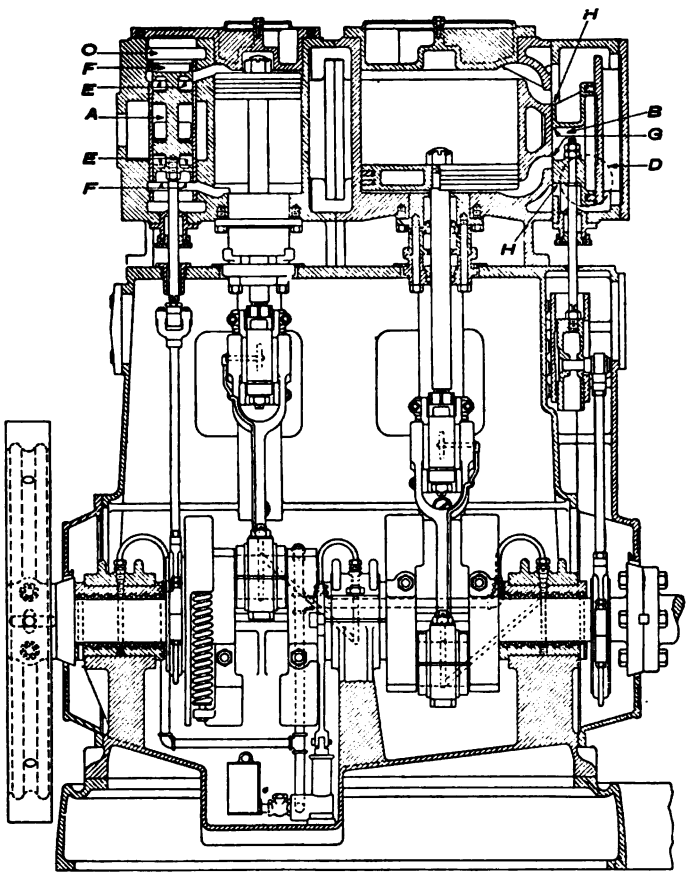


FIG. 248.—Vertical Section of Engine. Form H-2. Gen. Elec. Co.

The steam lap is $\frac{7}{8}$ inch top and bottom; the exhaust lap, top and bottom, is 0 inch. The travel of this valve is controlled by the automatic governor, and varies between $3\frac{3}{4}$ and $1\frac{5}{8}$ inches. The cut-off varies between $\frac{3}{4}$ and 0, depending upon the load.

Low-Pressure Valve.—The admission edges of the low-pressure valve are at *G*, and the exhaust edges at *H*.

The steam lap is $1\frac{1}{4}$ inches and the travel of the valve $3\frac{3}{4}$ inches, giving a cut-off of about $\frac{1}{2}$ stroke. The exhaust lap, top and bottom, is 0 inch.

Eccentric Rod and Strap.—Fig. 249 shows the high-pressure eccentric rod and strap with forked brasses which are in three pieces.

The low-pressure eccentric rod and strap are of the same general construction with the exception of the brasses which are in two instead of in three pieces.

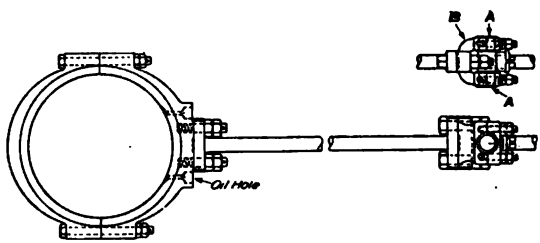


FIG. 249.—Eccentric Rod and Strap.

These brasses are secured to the upper end of the eccentric rod by two $\frac{3}{4}$-inch studs, while the lower end of the rod is secured to the top half of the strap by two studs of the same size.

The halves of the strap are kept a proper distance apart by liners which provide ample means of adjustment for wear and settings.

The bearing caps *A* are each secured by studs and double nuts. The wear is taken up by filing the cap faces.

The cast-iron guide for the high-pressure valve stem is bolted to the engine column, and is fitted with a composition metal bushing which is pressed into the guide.

Piston and Piston Packing.—The high-pressure piston is shown in Fig. 250, and is a cast-iron disk containing two rectangular grooves, which receive the piston packing consisting of three cast-iron arcs, overlapping at the ends and made steam-tight by brass tongues, one of which is riveted to each arc. The packing is held

tightly against the cylinder by flat springs $\frac{3}{8}$-inch wide and $\frac{1}{16}$-inch thick, which are fastened to the arcs by small machine screws. The piston fits on a taper and against a shoulder on the piston-rod and is secured by a nut on its upper side. The outer face of this nut contains radial grooves, one of which engages a split pin which prevents the nut from unscrewing.

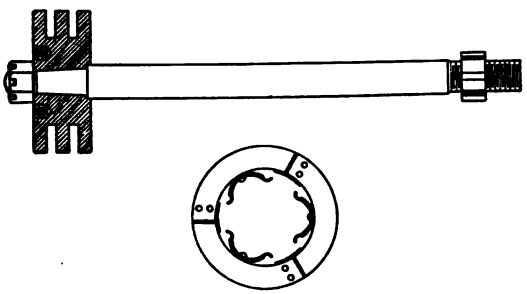


FIG. 250.—Piston, Piston-Rod and Piston Packing.

The low-pressure piston is also of cast iron, the general construction being the same as that for the high pressure, excepting that the packing is in four instead of in three sections, and that the piston is cored instead of being solid.

Piston-Rod.—The piston-rod (Fig. 250) is of nickel steel, and the diameter of both the high and the low-pressure rods is $2\frac{1}{4}$ inches. Each rod is threaded at the lower end which screws into the cross-head and is locked by a spanner jam nut.

Cross-Head.—The construction of the cross-head is plainly shown in Fig. 251. The body *A* is a mild steel forging. The cross-head shoe *B* is of composition metal, babbitted, and has a very liberal wearing surface so that the wear at this point will be very

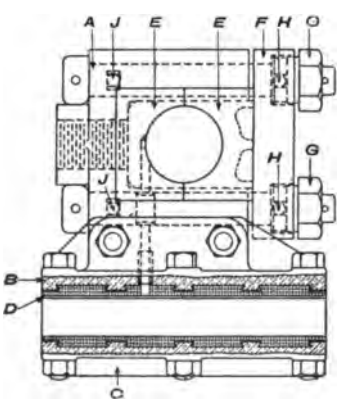


FIG. 251.—Cross-Head.

slight. The cross-head shoe is fastened to the cross-head by two 1-inch bolts and is held against the guide bar by the clamp *C* which is connected to the shoe by six through bolts, the proper distance between the shoe and clamps being maintained by adjustable liners *D*.

The cross-head is slotted to receive the wrist-pin bearing *E* which is made of gun metal, and is held in place by cap *F* and two bolts secured by lock-nuts *G*. The upper part of each nut is turned circular, and fits in a recess in the cap. Set-screws *H* prevent the nuts from turning, and set-screws *J* prevent the turning of the bolts.

Wear may be taken up by filing the edges of the brasses, and on account of the system of oiling which is used in this engine, it is important that these edges should always be together. The bearing

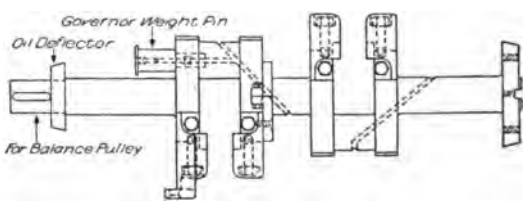


FIG. 252.—Crank-Shaft and Coupling.

should be so adjusted that when the brasses are hard together the wrist pin will move freely but without any play. Oil reaches the bearing from the oil pipe, passing up the side of the connecting rod; from this bearing it is further forced to the guide.

Crank-Shaft and Coupling.—The crank-shaft and coupling (Fig. 252) for transmitting the power to the generator, are made in one solid piece of forged steel with the crank-pins machined out.

Cast-iron counterbalance weights are fastened to each crank opposite the crank-pin, to balance the moving parts. Each weight is held by two bolts, one a cap bolt with the head sunk in the weight, the other a through bolt passing through the crank and secured by a nut.

One of these weights acts as a support for the adjusting screw of the governor spring.

One end of the shaft receives the balance pulley and the opposite

end holds part of the coupling. The two parts of the coupling are held together by four $1\frac{1}{4}$-inch bolts, and are forced apart by two $\frac{5}{8}$-inch set-screws when it is desired to disconnect the armature.

The radial key, 1-inch square, for transmitting the power, is secured to the face of the coupling by two $\frac{5}{16}$-inch flat-headed screws.

The shaft has a diameter of 5 inches at the bearings and $4\frac{1}{2}$ inches at the pulley end.

Throttle-Valve.—Fig. 253 illustrates the throttle-valve furnished with each engine. It is of the Lunkenheimer, regrinding type, and is $3\frac{1}{2}$ inches in diameter. The valve is fitted with a by-pass integral with the body. The valve stem is carried outside of the valve through the yoke, and a bolt and gland stuffing-box is used.

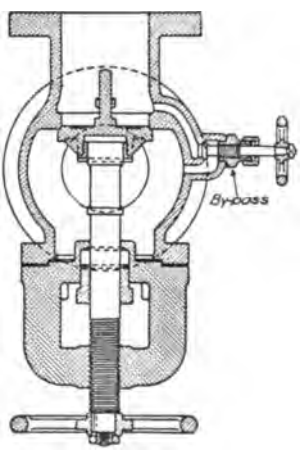


FIG. 253.—Throttle-Valve.

To regrind the valve seat when worn and leaky, proceed as follows: If the main valve, unbolt the bonnet, take the nut from the end of the stem, and remove the hand-wheel, after which remove the entire trimming from the valve body. The stem can then be unscrewed and drawn from the yoke. Prepare some abrasive material, such as a little powdered glass, sand or carborundum, mix it with oil, and apply this to the disk. Make the disk rigid with the stem by inserting a nail or piece of wire through the drilled hole below the lock-nut. The valve can then be reground by fastening the hand wheel to the stem, the extension of the disk being guided by a bridge in the body of the valve, which will enable the new seat bearing to be reground in perfect alignment. When the valve is reground, care should be taken to wipe off all the abrasive material from the seating surface, and to remove the wire pin from the disk. When properly reground, the valve will again be steam-tight.

The by-pass is not provided with a grinding-in guide, but, on

account of its small size ($\frac{1}{2}$ inch), and also on account of the spherical seat, the guide is hardly necessary. It can be reground by using the same abrasive.

All other valves used on this engine are of the same make, and of the union-bonnet construction, therefore it is necessary to remove the stem from the valve trimming, as the hub of the trimming should guide the body and keep the stem in line with the seat, otherwise the regrinding is accomplished as above noted.

Governor.—The governor is illustrated in Fig. 254, and consists of a single fly-weight *A* in halves which are securely bolted together and pivoted at *B* to the main bearing pin which is driven into the crank and secured by a set-screw as shown in the illustration of the crank-shaft. The fly-weight is supplied with a loose brass bushing which provides a double bearing surface. The pin and bushing communicate with the inside of the engine and are, therefore, always under an oil pressure which reduces to a minimum the danger of sticking or binding.

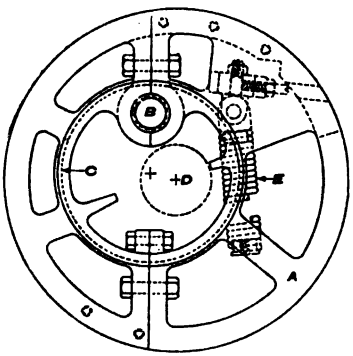


FIG. 254.—Governor.

The operation of the governor is as follows:

The eccentric rod and strap (Fig. 249) which transmit motion from the governor to the high-pressure valve are connected to the eccentric *C* forming a part of the weight casting. It is therefore evident that the length of the valve stroke depends upon the distance of the center of the eccentric *C* from the center of *D*.

The amount of steam admitted to the cylinder varies directly as the distance between the centers of *C* and *D;* that is, the less the distance the less the amount of steam admitted, and vice versa.

Suppose the speed of the engine to increase; the weight *A* is immediately drawn out by centrifugal force, thus decreasing the distance of the center of *C* from the center of *D* and reducing the amount of steam admitted to the cylinder. Should the speed of

the engine approach a dangerous point, the distance of D from the center of C will be diminished until the minimum distance is reached, when the steam is entirely cut off from the cylinder.

The motion of the fly-weight is opposed by the spring E which is attached to a bracket cast with the crank-shaft counterbalance. By increasing or decreasing the tension of the spring, the speed may

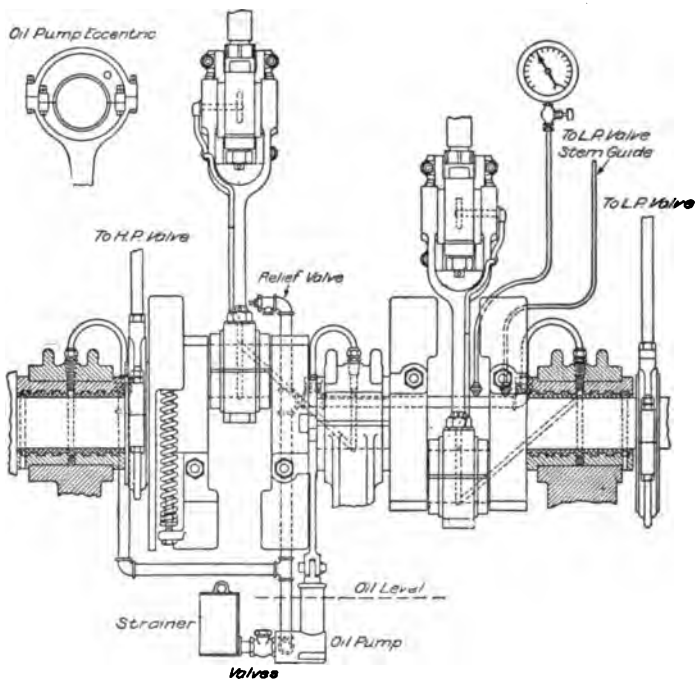


FIG. 255.—Lubricating Mechanism.

be raised or lowered. The same effect will be produced by moving the spring in the slot of the weight—moving it away from the fulcrum increases the speed and towards the center produces the opposite effect.

Unstable regulation is due, principally, to too close an adjustment of speed and may be avoided by moving the spring attachment away from the fulcrum.

The governor should occasionally be taken apart and cleaned, and care should be taken to see that the oil hole leading to the governor weight pin and bushing is kept free from all foreign substance. This is best accomplished by never allowing any waste or dirt to enter the inside of the column and thus find its way to the different bearings.

Lubrication.—The lubricant is carried under pressure to the various parts of the engine by the mechanism shown in Fig. 255 and will be understood from the description given for the form H-1 engine.

Indicator Motion.—When it is desired to indicate the engine, a small cover must be removed from the front of the column, exposing a slot over which a bracket containing a bearing pin for the levers is attached. Each cylinder has its own indicator motion consisting of a stud screwed into the wrist pin of the connecting rod for driving the motion, which connects through a link to a lever pivoted to the bracket covering the slot in the column. The motion for the indicator is taken from a cord pin on this lever.

Starting the Engine.—Before steam is admitted to the cylinders care must be taken to see that the valves move freely. This may be done by turning the balance pulley by hand. As the expansion of the valves is much more rapid than that of the cylinders, the cylinders should be allowed to attain their proper temperature before full pressure is applied. A by-pass valve ½ inch in diameter, integral with the body of the throttle-valve (see Fig. 253), is used for the purpose of heating the engine before starting. The drain from the steam chest together with all the cylinder-drain valves should be kept open, to allow all condensed water to escape.

If water hammering occurs after the engine is started, the cylinder-drain valves should be quickly opened.

Engines for Torpedo Boats.

These are made for generators of 2½ and 5-kilowatt capacity installed on torpedo-boat destroyers and torpedo boats. They are of the single cylinder, vertical, double-acting type designed for either 700 or 800 revolutions per minute at full load with 100 pounds steam pressure.

A generating set of 5 kilowatts using this engine is shown in Fig. 256. The engine is enclosed in a sheet-iron case which has been removed to show the moving parts.

There are no points of unusual detail in this engine, and the

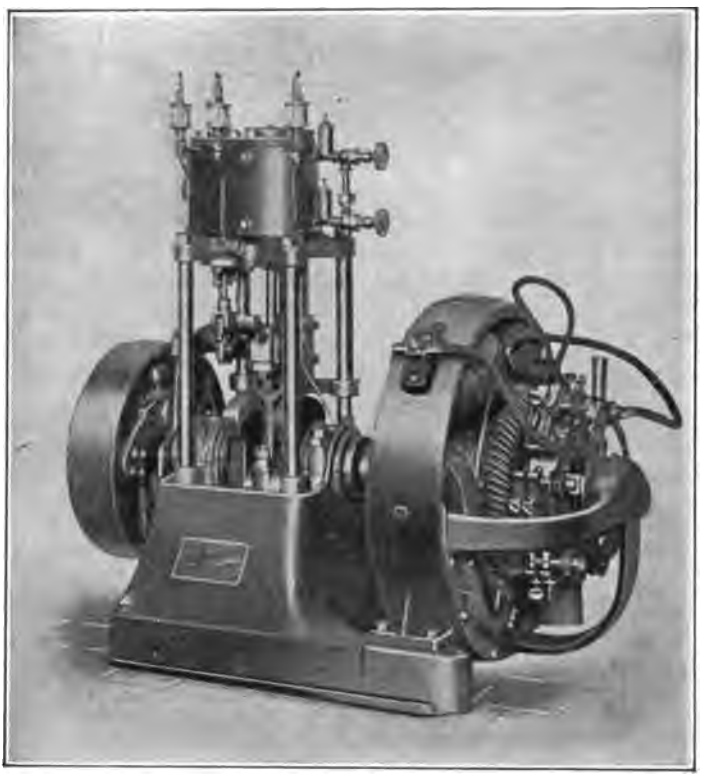


FIG. 256.—General Electric Company's M. P. 6-5-700, Generating Set.

only description given is that of the governor which is shown in Fig. 257.

The governor is a modification of the Rites design and is shown in Fig. 257. It is placed inside of the fly-wheel and on its outer side. The fly-wheel, *A*, is keyed to the shaft and carries the governor parts, consisting of: a weight *B*, pivoted at *C*; an eccentric *D*,

with counter-weight *E;* a coiled spring *F,* taking by a knife-edge on teeth at the upper side of the weight; and a link *G,* connecting the weight to the end of the bell crank of the counter-weight.

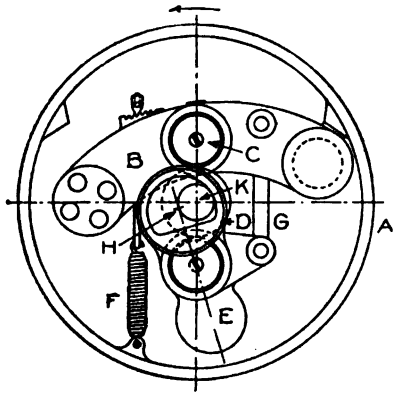


FIG. 257.—Governor.

The operation of the governor is as follows: The eccentric strap, which transmits motion from the governor to the valve, is connected to the eccentric *D;* the travel of the valve, therefore, depends upon the distance of *H* from the crank *K*. If the speed increases, the weight *B* is immediately thrown by centrifugal force toward the perimeter of *A,* decreasing the distance between *H* and *K* and shutting off steam from the cylinder; if the speed becomes too great the minimum distance between *H* and *K* is reached and practically all steam is shut off. Control of speed is effected by the tension of the spring, increasing the tension increases the speed and vice versa. The same effect will respectively be produced by moving the knife-edge suspension away from or towards the fulcrum *C*.

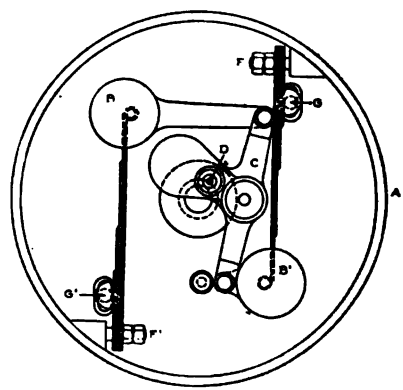


FIG. 258.—Governor.

The governor for the engine used with the 2½-kilowatt set is shown in Fig. 258.

The governor is a modification of the Rites design and is shown in Fig. 258. It is placed inside of the fly-wheel or pulley and on its upper side. The pulley *A* is keyed to the shaft and carries the governor parts, consisting of two weights *B* and *B'* connected to the opposite ends of

the lever C, on which is the pin D operating the valve. The centrifugal force of the weights is opposed by the leaf springs which are connected to the fly-wheel by the studs F and F' with double nuts, and which fulcrum on G and G'. The springs are held in place by flanges on the ends of the fulcrums.

The operation of the governor is as follows: The governor connecting rod which transmits the motion from the governor to the valve, is connected to D; the travel of the valve, therefore, depends upon the distance of D from the center of A. If the speed increases the weights B and B' are immediately thrown by centrifugal force toward the perimeter of A, decreasing the distance of D from the center of A and shutting off steam from the cylinder; when D and the center of A nearly coincide practically all steam is shut off.

Other Types of General Electric Engines.

Besides the types described, the General Electric Company furnishes engines that have been used on torpedo boats, auxiliaries, colliers, etc., called form A, B, C, D, etc. These are of a commercial type and are of the vertical, inverted, reciprocating, simple, condensing or non-condensing, double-acting type.

The Forbes Engine.

A section of a Forbes engine is shown in Fig. 259. It has several features differing from those previously described, among which are the kind of piston-rod packing, the form of governor and the control of the value by the governor.

The governor controls the *low-pressure* valve in the Forbes engine and not the high-pressure as in the types of the General Electric Company.

Governor.—There are two types of governor used with the Forbes engine, both constructed on the Rites design.

The weight embraces the greater part of a circle and is attached to a cross-arm pivoted as shown. The spring controls the centrifugal motion of the weight in the usual way. The fulcrum of the spring is adjustable in a slot. The action and adjustments are the same as for other governors built on the Rites design.

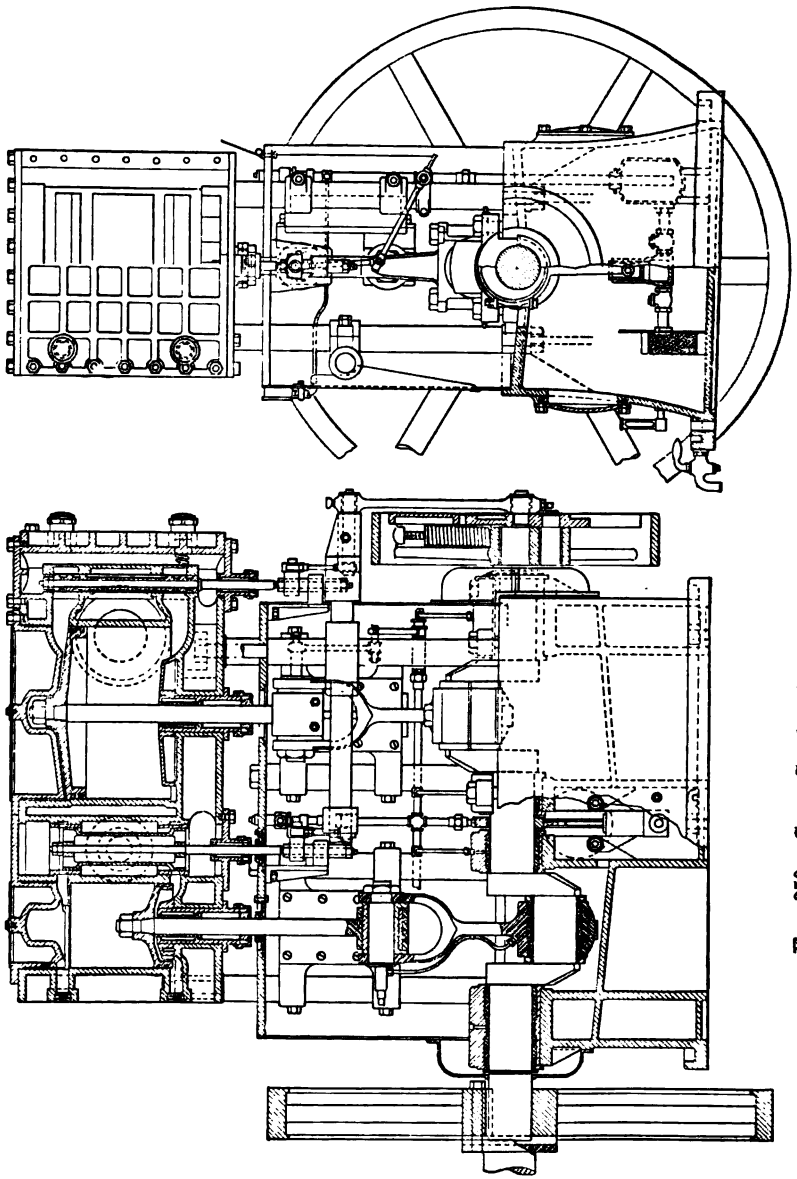


FIG. 259.—Cross-Section W. D. Forbes & Company Engine, 100 K. W.

The type used with smaller engine designs is shown in Fig. 260. It is a modification of the Corliss type of the Rites design. The governor standing part is an iron casting keyed to the shaft. At one side of the shaft is an extension which is bushed to form the bearing for a stud extending from the governor weight, and in the opposite direction is an extension which forms the outer point of attachment of the governor spring. The governor weight is a cam-shaped iron casting. The parts of the wheel face between the arms (or spokes) are arched out to reduce shrinkage strains, and to reduce, by a multiplied fluttering, the optical effect of the governor's eccentric rotation. To one of the six arms is attached a stud

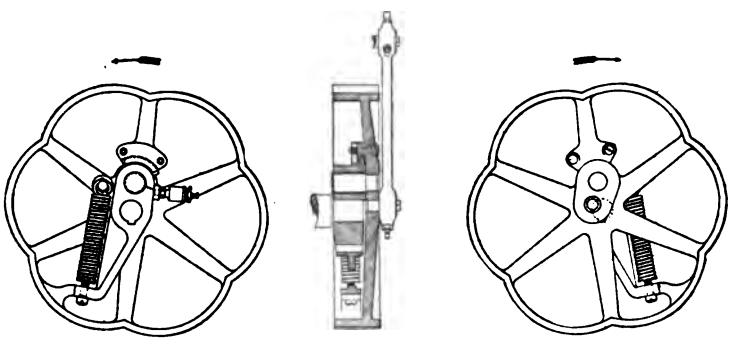


FIG. 260.—Governor for 24 K. W. and Below.

which forms the inner point of attachment of the governor spring. The eccentric pin is of machine steel and extends outwardly from the hub of the governor weight. The governor weight-retaining plate is a composition casting which is secured by two fillister-head machine screws to two extensions of one of the governor arms and engages with a projection at the governor standing part to keep the governor in position longitudinally on the stud. When any "sticking" occurs with this type of governor, it will usually be found in a too tight setting up of the cap nut that secures the weight.

The piston-rod packings are metallic, of the Katzenstein type; those on the high-pressure and low-pressure piston-rods are similar and of the "sectional self-acting" form, and are shown in Fig.

261. In the lower cylinder heads is a large bushing, *A*, which forms a guide for the piston-rod and a surface against which the packing rings are placed. Each ring has a serial number; the rings are placed in position in the sequence of their numbers. Rings No. 1, *B*, No. 3, *D*, and No. 5, *F*, are of bronze and cut in segments; these form conical surfaces forcing into place the packing rings No. 2, *C*, and No. 4, *E*, made of special anti-friction metal. Rings No. 2, *C*, and No. 4, *E*, are also cut in segments, in the placing, the joints are staggered with reference to the segments of

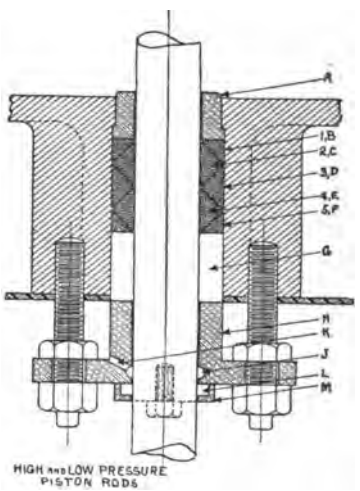


FIG. 261.—Katzenstein Metallic Packing.

rings No. 1, *B*, No. 3, *D*, and No. 5, *F*. It will be noted that rings No. 1, *B*, and No. 3, *D*, and No. 5, *F*, do not come in contact with the rod, but leave spaces between their edges in which the water of condensation may collect. In the space, *G*, below the rings, fibrous packing is placed, increasing the elasticity of the contact of the rings and facilitating lubrication. The gland, *H*, is of bronze and guides the piston-rods at their lower ends. A groove turned in at *J* is drilled with a drain hole, *K*. Below this is an auxiliary stuffing space, *L*, in which a turn of fibrous packing is placed and retained by the bronze gland *M*.

The B. F. Sturtevant Engine.

A cross-sectional view of one of the larger engines of this make is shown in Fig. 262.

It resembles in its general features the engine built under the same specifications by the General Electric Company. The **gover-**

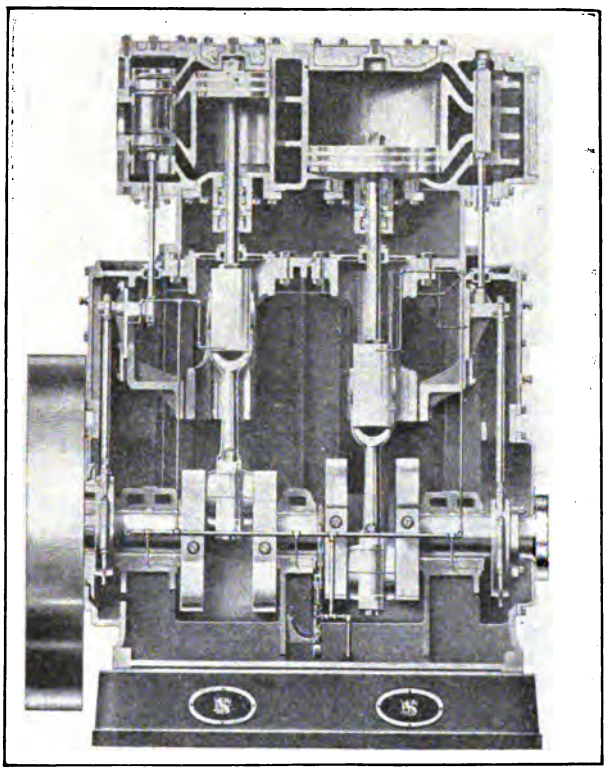


FIG. 262.—B. F. Sturtevant Company's Engine, 100 K. W.

nor is of the Rites "dumb-bell" type and is mounted on the outside and inside the fly-wheel. The governor controls the high-pressure valve and the high-pressure eccentric is mounted on a pin extending through the fly and governor wheel. As the weight flies out under the action of the centrifugal force, the eccentric is moved and the travel of the valve is shortened.

Steam Turbines.

The latest form of generator driving adopted is the steam turbine and generating sets of 300-kilowatt capacity with this form of motive power are now being built under the following specifications:

Turbine.

1. The turbine will be of the horizontal multi-stage type. It will be designed to run condensing with maximum practical efficiency at all loads. It will be of sufficient power to drive the generator for an extended time at the rated speed when said generator is carrying $1\frac{1}{3}$ load.

2. The normal steam pressure under which the turbine will operate, and at this steam pressure the maximum steam consumption in pounds per K.-W. hour for various degrees of vacuum, is:

K.-W.	Steam pressure.	25" Vac.	26" Vac.	27" Vac.	28" Vac.
300	265 gauge		26	25	$23\frac{1}{2}$

These rates should be interpreted as dry saturated steam, steam pressure being measured at throttle and vacuum in exhaust casing. Superheated steam shall not be used in the test.

3. The turbine to run smoothly and furnish the required power for full load at any steam pressure within 20 per cent (above or below) of those given in the table, and exhausting to condenser at 25 inches of vacuum; to furnish power for full load at any steam pressure between normal and 20 per cent above normal, when exhausting into the atmosphere. It will bear without injury the sudden throwing on or off of one and one-third times the rated load of the generator by making and breaking the generator's external circuit.

4. The steam inlets shall be so placed as to admit of piping from either side with equal facility. Blank flanges shall be furnished complete, when required to cover alternative outlets. Turbine to have exhaust outlet on right or left side as specified. All piping shall be firmly supported at points close to the turbine, so that the weight of same shall not affect the alignment of the parts involved.

5. Steam inlet valve shall be a combination throttle and emergency valve equipped with strainer intervening between valve and turbine steam line. It will be connected to the emergency governor in such a way that it will automatically close if the speed of the turbine rises more than 10 per cent above normal. Flange drilling to conform with specifications of the Bureau of Steam Engineering.

6. The governor will be of the centrifugal type operating a series of valves.

7. Lagging shall be fitted as extensively as practicable to turbine. It shall be done after a preliminary run of the turbine in order that any defects in casting or joints may be readily found. The arrangement for securing the lagging in place shall admit of its ready removal, repair, and replacement.

8. The speed variation will not exceed 2 per cent when load is varied betwen full load and no load gradually or in one step, turbine running with steam pressure normal or 20 per cent above normal, and exhausting into 28-inch vacuum. A variation of not more than 4 per cent will be allowed when full load is suddenly thrown on or off the generator with steam pressure constant between normal or 20 per cent above normal and exhausting into the atmosphere. No adjustment of the governor or throttle-valve during the test shall be necessary to insure proper performance under the above conditions.

9. The turbines will operate without the use of lubricants in the steam spaces. Forced lubrication will be used on all bearings. The bed-plates will contain an oil reservoir from which oil will be drawn by a pump operating directly from the main shaft, and forced through the system. To be provided with a strainer which may be removed without interrupting the oil supply. The oil will be cooled by water which will pass through a coil around which the oil will circulate.

10. Mandrels, with collars, complete, will be furnished for renewing the white metal of all bearings so fitted.

11. The material and design of the turbine will be such as to safely withstand all strains induced by operation at the maximum steam pressure specified.

12. The maximum allowable normal speed, weight and over all dimensions of the complete generating set, of which the turbine forms the motive power are:

Size in K.-W.	R. P. M.	Weight in lbs.	Overall length.	Max. width over pipe connections.	Width.	Height.
300	1500	28,000	155″	100″	76″	90″

Elementary Theory of the Curtis Steam Turbine.

The following general theory of the steam turbine is taken from a paper on "The Curtis Vertical Steam Turbine" by Charles B. Burleigh of Boston, Mass., and reproduced by permission of the author:

"The Curtis turbine bears a strong resemblance to a water-wheel and most of the principles involved are applicable to both. The widest difference, however, between steam and water is in the speed at which they move under pressure.

"The velocity of a jet of water at 150 pounds pressure per square inch, which is equal to a head of 346 feet, is approximately 149 feet per second, while steam expanded from 150 pounds pressure per square inch to the pressure of the atmosphere attains a speed of 2950 feet per second and if expanded into a 28-inch vacuum can attain a velocity of 4010 feet per second. It will, therefore, be noted that the speed of steam is 19 times that of water at 150 pounds pressure.

"There are certain fixed laws governing wheels actuated by fluids which are productive of the best results: the buckets should, to produce the best results, move at one-half the speed of the fluid which actuates them and any departure from this condition results in lessened efficiency. There should be no shock between the buckets and the fluid, no sharp angular deflection to suddenly change the direction of motion of the fluid; there should be as little friction as possible between the buckets and fluid.

"There are many other characteristics of importance which will become apparent as we continue.

"**Velocity of Steam.**—As in actuating the turbine we are interested only in the velocity and volume of the steam and have no interest in the expansion other than for the production of the resulting speed and from the fact that until the comparatively recent development of the turbine, steam engineers have paid little or no attention to this characteristic, it may be well to briefly discuss it.

"Let us consider a given volume of steam at a given pressure, confined in a vessel surrounded by a similar vessel in which the pressure is equal to that of the steam in the inner vessel. For the sake of simplifying the illustration, disregard temperature. If we effect an opening in the inner vessel no steam will escape into the outer one, for the reason that the pressures are balanced. Now, if by any means we lower the pressure in the outer vessel equilibrium is destroyed and the steam immediately expands to this lower pressure, just as it does in the engine cylinder behind the moving piston.

"The steam cannot expand without displacement of the medium before it and the energy of expansion is utilized in producing motion in the steam mass.

"The steam in its confined state was possessed of potential energy and on expanding a part of this potential energy was converted into kinetic energy or velocity.

"It is a fact not generally appreciated that this kinetic energy generated by the expansion of a given weight of steam depends upon the number of times the steam is expanded and not upon the particular pressures between which it is expanded; or, in other words, 1 pound of steam expanded from 4 to 2 inches absolute pressure (26 to a 28-inch vacuum) at atmospheric pressure of 30 inches of mercury or from 2 pounds to 1 pound absolute, is capable of as much work as expanding the same pound of steam from 150 pounds to 75 pounds pressure. This is very clearly illustrated in diagrammatical form in an article written and published in 'Power,' October 9, 1905, by its editor, Mr. Fred. R. Low.

"Without expansion, steam is incapable of motion, but other things being equal its motion is in accordance with its expansion, that is, its acceleration is increased as the difference in pressures between which it is expanded is increased.

"In the Curtis turbine the steam is expanded in a series of expanding nozzles so designed that they will expand it between such pressures as will give to the steam the desired velocity to which we shall refer more in detail later.

"For the present, let us consider two facts:

"First. That steam expanded from 150 pounds pressure to that of the atmosphere will acquire a velocity of 2950 feet per second.

"Second. That in order to efficiently utilize this velocity it is necessary that the actuated medium (the buckets) move at a speed one-half that of the steam actuating them. Therefore, in this case, the bucket speed to meet these conditions must be 1475 feet per second. Let us consider these buckets milled on the periphery of a wheel 1 foot in diameter and it will at once become apparent that this wheel must rotate at a speed equal to a circumferential speed of 1475 feet per second, which would result in a shaft speed of $\frac{1475 \times 60}{3.1416} = 28{,}170.3$ revolutions per minute.

"It is obvious from the foregoing that a means must be devised whereby we shall be enabled to overcome this excessive speed. In

order to arrive at a solution of this problem in proper sequence let us more fully investigate the interaction of the buckets and steam and their effect on each other.

"The shape of the Curtis bucket may best be compared to a vertical new moon, so arranged that the steam is brought in contact with it at the top, at an angle corresponding closely to the arc of the buckets. When the flowing steam is brought in contact with the buckets, which, due to their shape, tend to change its direction of flow, it tends to move these buckets.

"Neglecting losses the velocity of the steam on leaving the bucket equals the velocity at which it enters it.

"If the bucket is in motion the nozzle delivering the steam being stationary, the velocity of the steam leaving the bucket will, instead of equalling the entrance velocity, equal the difference between the bucket velocity and the entrance velocity; that is, the steam in travelling faster than the bucket, and following around the curve of the bucket, leaves it with a velocity relative to the bucket, the same as that at which it entered.

"Mr. J. G. Callan, of Lynn, gave an explanation of this in a recent lecture which describes this action most clearly: 'Steam enters the bucket at velocity V_1, follows the arc of the bucket and neglecting losses, the velocity which is left is V_2.

"'The weight of the steam has remained unchanged and since the energy of a moving body is one-half the mass, times its velocity squared, the energy possessed by the steam as it goes into the bucket is $\frac{MV_1^2}{2}$. Its energy as it comes out is $\frac{MV_2^2}{2}$ and the energy given up for the bucket is $\left(\frac{MV_1^2}{2}\right) - \left(\frac{MV_2^2}{2}\right)$.

"'This has been given up to the buckets because the steam was pushing while the buckets were moving.

"'If the buckets had been stationary it would have simply changed the direction of the steam without material loss of energy, as it would have entered at a velocity of V_1 and left it at practically the same velocity.

"'Do not understand that the steam would not tend to actuate the stationary bucket, for it would, for the pressure on the bucket

is greater when the bucket is stationary and is reduced as the bucket moves away from the steam, as the steam pushes the bucket under these conditions with the lessened velocity.

"'If the bucket is held stationary no work is being done. Work is represented by the formula $\frac{MV^2}{2}$, also by FS or force multiplied by space.

"'If force acted upon the bucket without moving it, no work would be done. The steam delivered by the nozzle is moving so fast that it is not at all inconvenienced in keeping up its push on buckets moving at a high speed, and as we increase the velocity of the bucket the steam is able to follow it and tends to push it forward up to a velocity equal to that of itself; if the speed of the bucket reaches that of the steam the steam would simply follow it without pushing at all. Bear in mind that it is the proportion of the volume of the steam to the resistance to the movement of the bucket which determines the speed of the bucket.

"'From the foregoing it is easy to determine the best speed conditions. When the bucket is stationary the push is greatest and its velocity is zero and when the speed of both the steam and the bucket are equal the velocity is greatest and the push is zero; at both these extremes the work done is zero.

"'There is a point between these two extremes where the effect will be maximum. That point will be where the energy remaining in the steam after it has passed through the bucket will be the least.

"'Now let us assume that V_1 is just twice the velocity of the bucket, then subtracting this bucket velocity from the steam velocity, leaving the remainder as the speed of overtaking, and then subtract the same bucket velocity from it again and we shall have subtracted the half of V_1 twice and V_2 will become zero; in other words, with the bucket moving at one-half the speed of the steam which actuates it the velocity remaining in the steam is zero and it is clear that we have obtained maximum efficiency.

"'But as previously stated, we are in trouble due to the excessive shaft speed resulting from the bucket speed necessary to maintain these conditions. There are two methods by which we can reduce our shaft speed without resorting to gears: First. We can cause

the steam to acquire its full velocity, cause it to actuate the buckets of the first moving wheel and give up a certain amount of velocity, then pass it through stationary re-directing blades and cause it to actuate the buckets of a second wheel and give up to it more of its velocity and pass it on by the same method to a third and even a fourth wheel.

"'Another method is to utilize during the first step part of the energy of the steam for acceleration, that is to say, expand it from boiler pressure to say one-half or one-quarter of the exhaust pressure.

"'It is obvious that by this method we have transformed only a part of the potential energy of the steam into kinetic energy and by so doing have caused the steam to move at a proportionately lower speed.

"'We may now expand it further by as many steps as are found to be desirable. Either of the foregoing methods will result in enabling us to reduce our shaft speed. Considering the second method, suppose we take a four-stage turbine compared with a single stage, with one wheel per stage in each. It would appear at first glance that by the use of four stages we should reduce our shaft speed in the ratio of four to one, but this would not be the case. The steam admitted to each of the four stages will have one-quarter of the total energy, equal to one-half of the steam velocity, which would result, if all the energy were used to produce velocity in one stage. Now the economical wheel must move at a peripheral speed which is proportional to the velocity and not the energy of the steam which actuates it and as the steam velocity has only been halved by using four stages, we have only reduced our shaft speed by a like amount, assuming a single wheel per stage.

"'Therefore, by this method shaft speed is reduced as the square root of the number of stages used.

"'Let us now investigate the first method of reducing shaft speed. If, as before stated, we expand the steam completely in the nozzle and obtain full velocity, and actuate but one wheel with it, the wheel must move at a peripheral speed equal to about one-half of the velocity of the steam, in order to produce the best results. Now if we can devise a means by which we can redirect the steam

as it emerges from this wheel and bring it in contact with a second wheel, this second wheel moving at the same speed and in the same direction as the first, will extract practically the same amount of velocity from the steam, so each of the two wheels need have but half the peripheral velocity of the single wheel. Therefore, by the use of two wheels, we reduce the shaft speed to one-half. Now let us combine the two methods and note the result.

"'Let us expand our steam from boiler pressure in a set of admission nozzles to, say, within three-quarters of exhaust pressure and with it actuate the buckets of a first-moving wheel, where it will give up a certain amount of velocity, then pass it through a set of stationary redirecting blades, and cause it to actuate the buckets of a second wheel which shall abstract the balance of its velocity. After leaving this second wheel the kinetic energy of the steam is exhausted but it still possesses potential energy, from the fact that it is capable of further expansion.

"'We have now passed what is termed the first stage. Let us now deliver the steam to a second set of expanding nozzles which will permit it to expand to within one-half of the exhaust pressure, thus giving velocity to the steam equal to the first expansion, and deliver it to two similar wheels and set of redirecting vanes where the same process is repeated, resulting in the velocity being reduced to zero and the steam brought to rest.

"'We have now passed what is termed the second stage, but the steam still possesses potential energy, being capable of further expansion.

"'We now deliver it to a third set of nozzles which expand it to within one-quarter of exhaust pressure, thus producing a steam velocity equal to each of the previous expansions and deliver it to two more wheels and set of redirecting vanes, with the same result, passing now what is termed the third stage.

"'Here we deliver the steam to a fourth set of nozzles which expand it to exhaust pressure, again imparting to it a velocity equal to what it possessed on entering each of the three previous stages, which velocity is abstracted in a similar manner by two more wheels and set of redirecting vanes. We have now passed what is termed the fourth stage, and have abstracted from the steam all of its energy. Now let us see what we have accomplished.

"'Our bucket speed is, in each case, half our steam speed and we have halved this twice, first by doubling our number of wheels per stage and second by increasing the number of stages. This has resulted in a very comfortable bucket speed and, due to the diameter of the wheels, we are enabled to use with this design, a very reasonable shaft speed.'"

Oil Engines.

Oil engines are used in shore wireless stations as power for generator driving at such places where a steam plant is not necessary for other purposes. These engines are always ready for use,

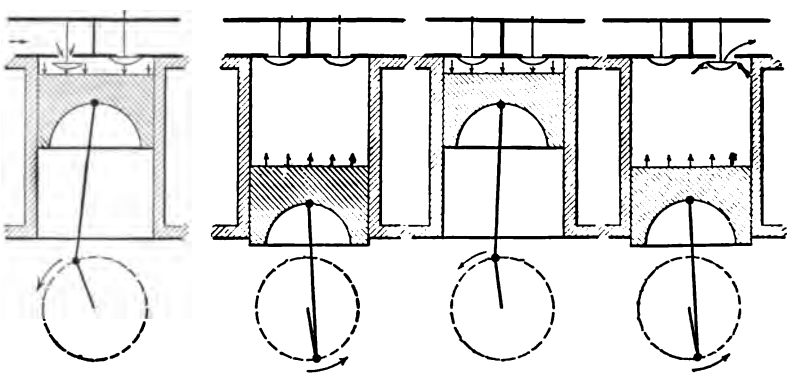


FIG. 263.—Four-Cycle Compression.

are simple in construction and do not require expert care or attention.

A form of engine using oil as fuel extensively used in such isolated places as wireless stations is of the Hornsby-Akroyd make, built on the Otto cycle, or four-cycle compression type.

The operation of a four-cycle compression is illustrated in Fig. 263.

First Period. Admission of the Charge.—The piston is driven down and a vacuum is created behind it through which the charge is drawn as shown by the open admission valve. This charge may be air and gas or vapor, and is drawn in throughout the first stroke of the piston.

Second Period. Compression.—On the start of the return stroke

the admission and exhaust valves are closed, so that the mixture drawn in during the first stroke is compressed in the clearance space between the end of the cylinder and the piston.

Third Period. Ignition.—At the end of the second stroke, the compressed mixture is ignited and the expulsion due to its explosion drives the piston to the end of the third stroke.

Fourth Period. Exhaust.—On the return of the piston on the second stroke, the products of the combustion are discharged through the exhaust valve.

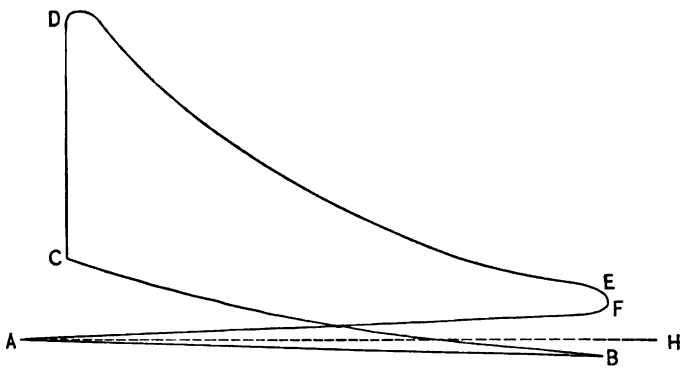


FIG. 264.—Indicator Card of Otto Cycle.

This constitutes the four-period operation, each complete operation consisting of four distinct periods, during which time the engine makes four strokes and two revolutions, and during which there is one explosion.

Indicator Card.—The distinct operations taking place during one explosion can be seen from a typical indicator card shown in Fig. 264.

AH represents the atmospheric pressure. From *A* to *B* the charge is drawn in on the first stroke of the piston and the pressure falls slightly below the atmospheric pressure. During this time the admission valve is open and the exhaust closed. The line *BC* represents the pressure line due to the compression on the second stroke, and *AC* is the pressure of the charge due to the compression. During this operation both admission and exhaust valves are closed. The line *CD* represents the increase of pressure due to the igni-

tion of the mixture, *DE* is the fall of pressure due to onward motion of the piston in the third stroke, and at *E*, the exhaust valve opens and the pressure falls according to the line *EF*. On the fourth stroke, the exhaust valve is open and the products of combustion are discharged, the pressure falling according to the line *FA*, returning to the starting point. This operation is then repeated over and over again.

The Hornsby-Akroyd Engine.—This make of engine is of the four-cycle type and uses kerosene or any heavy mineral oil as fuel. A sectional view of this engine is shown in Fig. 265 showing the cylinder and combustion chamber. *A* represents the compression space into which the piston does not enter. Secured to the end of this compression chamber is the receptacle *B* which acts as a vaporizer and exploder. In this engine the charge is exploded by spontaneous ignition, the walls of the vaporizer being kept at a red heat by the combustion of the oil. To start the engine the vaporizer is heated by a lamp until brought to a red heat, when the lamp is extinguished and the engine started by hand. After once started the heat of the vaporizer is maintained by the heat due to the explosion.

On the first or suction stroke a small quantity of oil is injected through a nipple directly into vaporizer, where it is vaporized by the intense heat. At the same time oil is injected the air valve is opened. At the end of the suction stroke the cylinder is filled with air and the vaporizer with oil vapor. During the compression stroke the air is compressed into the vaporizer where it mixes with the oil vapor and forms an explosive mixture, where it is ignited by the hot walls of the vaporizer. During the third stroke, the cylinder is filled with the products of the explosive mixture and on the fourth stroke all these products are forced out through the exhaust valve and another injection of oil takes place.

The half of the vaporizer nearest the cylinder is covered with a water jacket, the other half unjacketed to maintain the red heat required.

There is no vaporization until the oil is actually in the combustion chamber and the density of the oil is of no importance and light or heavy mineral oils may be used. The oil supply is

regulated by a governor and if the speed exceeds the normal the mechanism opens a by-pass valve which reduces the charge entering the vaporizer and the mean pressure developed in the cylinder.

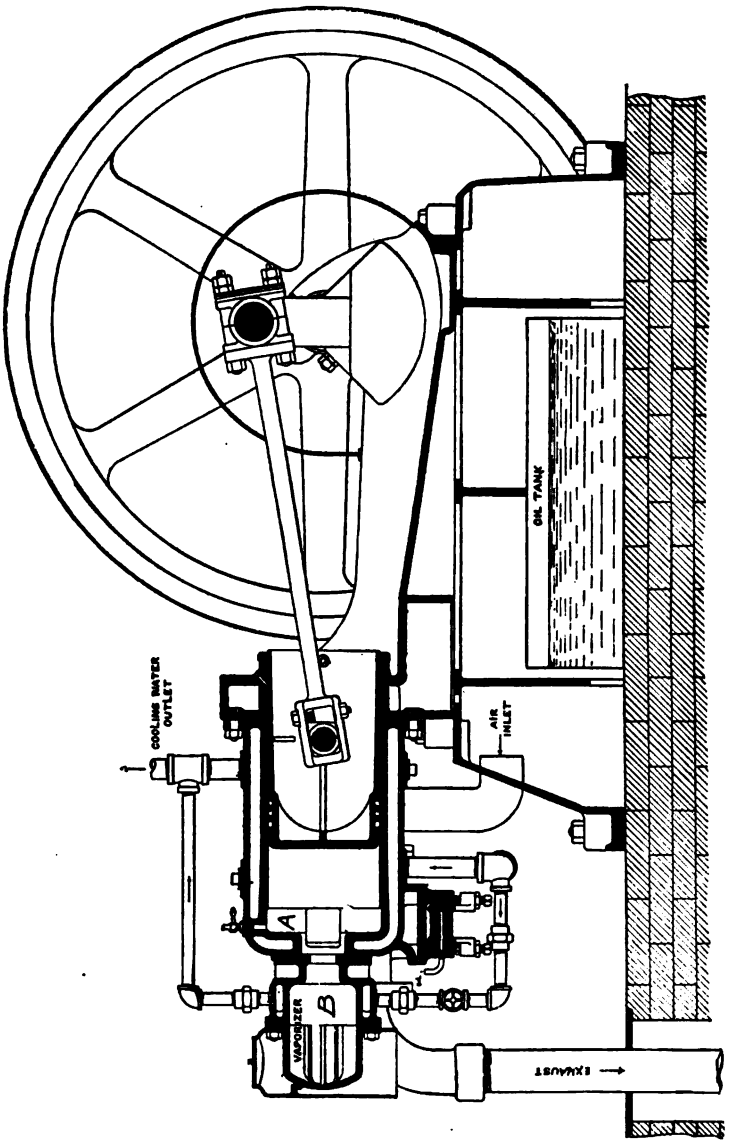


FIG. 265.

CHAPTER XXIII.

SWITCHBOARDS AND DISTRIBUTION PANELS.

The general idea of a switchboard is to distribute the generator current throughout the ship according to some previously-designed plan; the method of distribution depending upon the total power and the purposes for which it is to be utilized; whether for lighting power or search-light purposes, or any or all of them. In the early days of ship lighting the demand for current was small and the distribution very simple, usually one generator being sufficient to furnish all the desired current, and the switchboards were very simple, but very massive affairs. As the demands for current increased and the search-lights were furnished from the same source of power as the incandescent lights, one generator was not sufficient, so means had to be adopted of providing a switchboard that would distribute current for both kinds of lighting in parallel and to furnish a means of connecting the generators in parallel.

A standard switchboard was adopted which was installed on many ships, and even now is to be met with frequently. The details of the switchboard proper are shown in Fig. 266.

Fig. 266 represents a switchboard for two generators. On the board which is made of slate are mounted six vertical bus bars, the outside ones being connected together by a cable on the back of the board, shown by the dotted lines. This makes a common + bar for both generators, a generator lead from each positive terminal leading to the terminals of the bus bars. The four inside bus bars are negative bars, and they are connected to each other as shown by the dotted lines, representing connecting cables. This has the effect of making simply two negative bars, adjoining bars being connected to different machines. There are two terminals at the bottom of the board to which are connected the equalizer leads from the brushes of each machine. The negative bars of the

two machines may be connected by a double switch as shown at the bottom of the board, one leg of the switch connecting the negative bars, the other the equalizer terminals.

Circuit feeders leading from the switchboard to their feeding

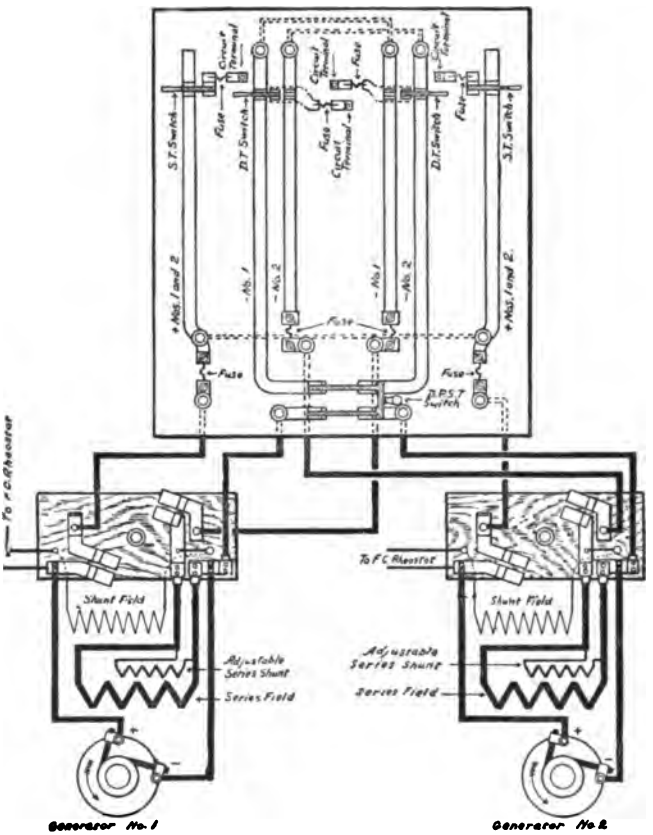


FIG. 266.—Early Type of Switchboard.

centers are shown at the top of the board on each side. The positive leg is connected to the positive bar by a single-throw switch through a fuse, and the negative leg is carried through a fuse to a terminal between the negative bar of the two machines. Here it is

connected to a double-throw single-pole switch, by which either machine may be utilized to supply current to the section. To throw from one machine to the other, it is simply necessary to throw over the switch.

The main bus bars are fused at their positive and negative terminals, these fuses carrying the whole current from the generators.

To connect the machines in parallel, it is only necessary to connect the negative bars and the equalizer terminals, as the positive are permanently connected, and this is done by simply closing the double switch.

If there are three generators, the only alteration in the switchboard is the addition of another negative bus bar, and a common equalizer bar at the bottom by which any combination of the three can be put in parallel.

Instrument Boards.—As a part of this switchboard, on each side of it are installed boards, similar in construction to the main switchboard, containing the instruments for use with the generators. One of these contained a lamp ground detector, a voltmeter that could be connected to either set of bus bars by a shifting switch, and an ammeter for each machine in series with the main leads. The other board contained the voltmeters and ammeters for the search-light circuits, there being one of each for each search-light.

The shunt field rheostats were placed conveniently below the main switchboard and the resistances of the search-lights near their instrument board.

Switchboard for Small Vessels.

A type of switchboard used on a few small vessels of the gunboat class is shown in Fig. 267.

There are three horizontal bus bars, one positive, one negative and one equalizer bar. There are two vertical bus bars, one being connected to the horizontal positive bar and one to the negative bar. Connected to these vertical bus bars are horizontal section bars, one of each set connected to the vertical positive bar, the other to the vertical negative bar. The horizontal section bars are flat on the back of the board and also one horizontal bus bar; the vertical bars, equalizer and one horizontal bus bar being raised from the board,

the connections between them being made by threaded bolts. The connections are indicated by the small black squares.

The positive, negative and equalizer switch for each generator

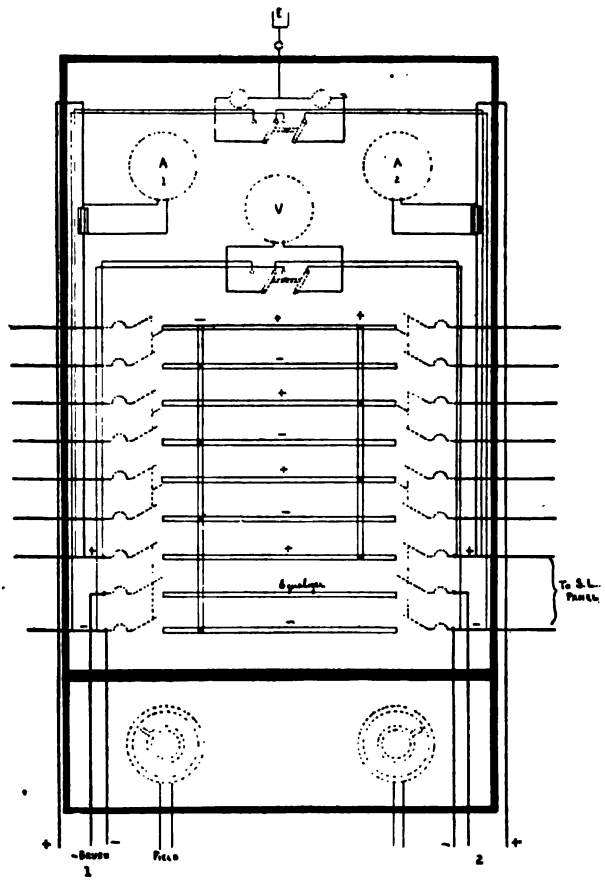


FIG. 267.—Switchboard for Gun Boats.

are all connected, one motion closing all three. The positive and negative section switches are connected and one motion closes or opens both. Each generator lead is protected by a fuse on the board and each leg of each circuit as represented.

A, A, represents the ammeters, one for each generator connected to an ampere shunt on the board. *V* is a voltmeter which is connected to indicate the voltage of either machine by means of the shifting switch. The same switch arrangement is used on the ground detector shown above the voltmeter. The leading wires for these instruments are connected to the switchboard terminals inside the main switches so they indicate when those switches are open.

Below the switches and bus bars are shown the shunt field rheostats.

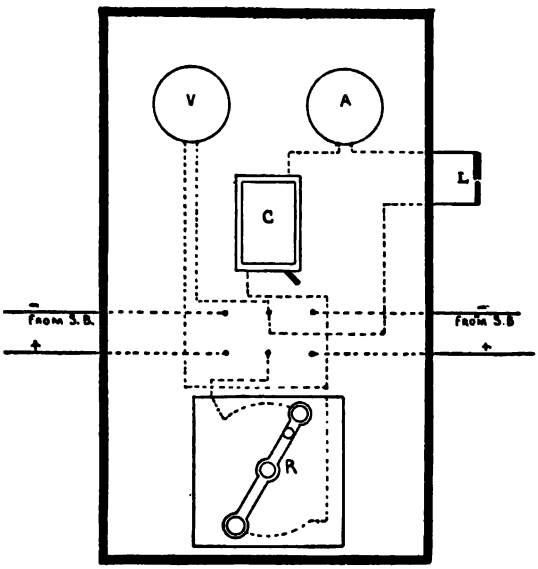


FIG. 268.—Connections of Search-light Panel.

If both machines are running they must run in parallel, for closing both main switches connects them so, at the same time connecting the brushes of the machines through the equalizer.

In this figure all the bus and section bars and leading wires are behind the board, the instruments, switches, switch clips, fuses and rheostat arms only showing on the front.

Search-Light Panel.—In vessels of a size having such a designed switchboard it is usual to install one search-light, a separate panel being used for the instruments as shown in Fig. 268.

The leads for the search-lights for each generator are taken from the switchboard terminals on the generator side of the main switches to contacts on the search-light panel. The search-light terminals are connected to the center contacts to which are attached a double-pole, double-throw switch, so the light can be supplied from either generator. One generator can be supplying current for lights, while the other is running the search-light, both running separately, the main switch of the generator on the search-light being open, or it can be closed when the two will run in parallel. One center contact is in connection with the variable resistance *R*, from which the current flows through the circuit breaker *C*, ammeter *A*, through the arc *L* and back to the other center contact. The voltmeter is connected to show the voltage at the lamp terminals, the drop from the generator voltage being due to the resistance *R*. In this panel only the instrument's circuit breaker and rheostat show on the face of the board, the leads and connections are on the back. The front view is shown.

These two designs of switchboards will illustrate the general idea of what is expected of a switchboard, being more complex in its construction as the demands are greater. The method of distribution is again referred to under the subject, Wiring, showing plainly that what is sufficient for one class of ships may be totally inefficient for another. In present ships not only are there main switchboards but auxiliary ones, called distribution switchboards, situated near the extremities of the ship far removed from the generator-room.

However the designs may differ, the requirements may be the same, and switchboards are now made under specifications of the Bureau of Equipment from which the following is copied:

General Specifications.

"The design of the switchboard in general to be such that any generator or any combination of generators operating in parallel may be run on any circuit or any combination of circuits. These circuits are search-light, light, power and one for each turret, the operation of whose electrical-turning mechanism requires a separate generator.

"For the larger installations the switchboard shall have a generator panel, a lighting distribution panel, a power distribution panel and a search-light panel. The first three to be continuous and form one board. The last may be separated from the main board.

"When the installation consists of two generating sets only, the lighting distribution panel, the power distribution panel and possibly the search-light panel may be combined. Should the installation consist of one generating set only, and that not larger than 8 kilowatts the entire switchboard may be installed as one panel.

"The switchboard is to be arranged for connecting the negative lead of each machine to a horizontal common negative bus bar by a single-throw, single-pole switch.

"When generators are more than three in number, each one is to be arranged for connection to each of two horizontal equalizer bus bars by means of single-pole, single-throw switches.

"To have only one equalizer bus when installation consists of three generators and a single equalizing switch when of two generators.

"To have a vertical bus bar for the positive leads of each generator and a horizontal bus bar for each circuit, *i. e.*, one for search-lights, one for lights and one for power.

"At each crossing point of these two sets of bus bars, connection is to be made by means of single-pole, single-throw switches.

"The arrangement of the generator panel to be such that all the switches and instruments necessary for the control of one generator shall be in a vertical line, and shall consist of (starting from top) a single-pole automatic circuit breaker, an ammeter shunt, an ammeter, handle for operating field regulator, voltmeter receptacle, such field-controlling switches as the turret system may require, positive generator switches connecting to circuit bus bars, switch to common negative bus bars, switches to equalizer bars and lastly a switch for shunting around the series field of generator when turret-turning system so requires.

"Arrangement of voltmeters to allow the voltage of any generator to be read on either of two voltmeters; to allow all the voltmeters to be interconnected for calibration; to allow the simulta-

neous reading of the voltage of as many generators as it may be desired to connect in parallel at any one time.

"Light distribution panel to contain a double-pole switch, fused for each lighting circuit, a main negative lighting switch, and when a separate search-light panel is used the light distribution panel is to contain a main negative search-light switch.

"Each search-light to have its own ammeter, double-pole automatic circuit breaker and regulating resistance.

"Switchboard to be provided with a lamp ground detector with switch for breaking ground connection. In addition a voltmeter ground detector is to be provided with leads to assist in determining circuit which the ground is on.

"All circuits to terminate and all connections to be made on the back of the board."

Standard Switchboard.

The switchboard designed under the preceding specifications is the one now installed as the standard, and the following detailed description with accompanying figures will make its operation clear. This description is for a plant of eight generators and five circuit bus bars.

This switchboard is adapted for use on board ships having two electrically-operated turrets, and in case it is used on ships which have no turrets, the general arrangement need not be changed, but all such switches and the like, as may be essential for turret turning only, should be omitted.

The general arrangement is such as to allow any number or combination of generators to run on any circuit or any combination of circuits. These circuits are five in number, namely, search-light, lighting, power, forward turret turning and after turret turning.

To accomplish this, the negative pole of each machine can be connected by a single-pole, single-throw switch to a horizontal common negative bus bar, whereas there are eight vertical positive generator bus bars, one for each generator. Back of these eight bars are five horizontal circuit bus bars, and where these two sets cross ($5 \times 8 = 40$ points) there are single-pole single-throw switches which allow the positive leg of each, any or all generators to be connected to each, any or all circuits.

For paralleling generators there are two separate equalizer bus bars, one for lighting and another for power (there will be no occasion for paralleling machines on search-light or turret-turning circuits). Such generators as may be desired are connected to these equalizer bus bars by removable blade plug switches.

When a generator is used to operate the turret-turning motors, the series field is short-circuited through a special German silver shunt, in addition to the shunt used on the generator itself. This is accomplished by single-pole single-throw switches at the base of board, one switch to each machine.

Referring to Fig. 269, each of the generator panels is arranged in four vertical sections, each section containing all the apparatus necessary for the operation of its own generator. Starting at the top we have a single-pole automatic circuit breaker, connected in on the positive leg of the generator (handle of circuit breaker must be within 6 feet of deck), then the ammeter shunt (on back of board), then the ammeter and wheel for operating the field regulator, wheel connected to rheostat by sprocket chain. Next comes the plug receptacle for connecting to voltmeters, and then the field-control switches, three pairs of single-pole single-throw switches (description of last two devices follows later). Next come five single-pole single-throw positive generator switches by means of which the generator may be connected to (proceeding in order starting with the upper switch) 1st, search-light bus; 2d, lighting bus; 3d, power bus; 4th, forward turret bus; 5th, after turret bus. In the same vertical row but on lower panel there are four single-pole single-throw switches; the upper one connects the negative leg of the generator to the common negative bus bar, the two middle switches connect the equalizer bars, and the lower switch is to shunt the series field for turret turning, as previously mentioned.

At the left of the generator panels is the power distribution panel, containing as many double-pole single-throw fused switches as may be required. Arranged at the top of this panel is a ground detector with receptacle, also two voltmeters, with plug receptacle underneath. In the center of the power panel is a main negative power switch, single pole, single throw, while on each side are two

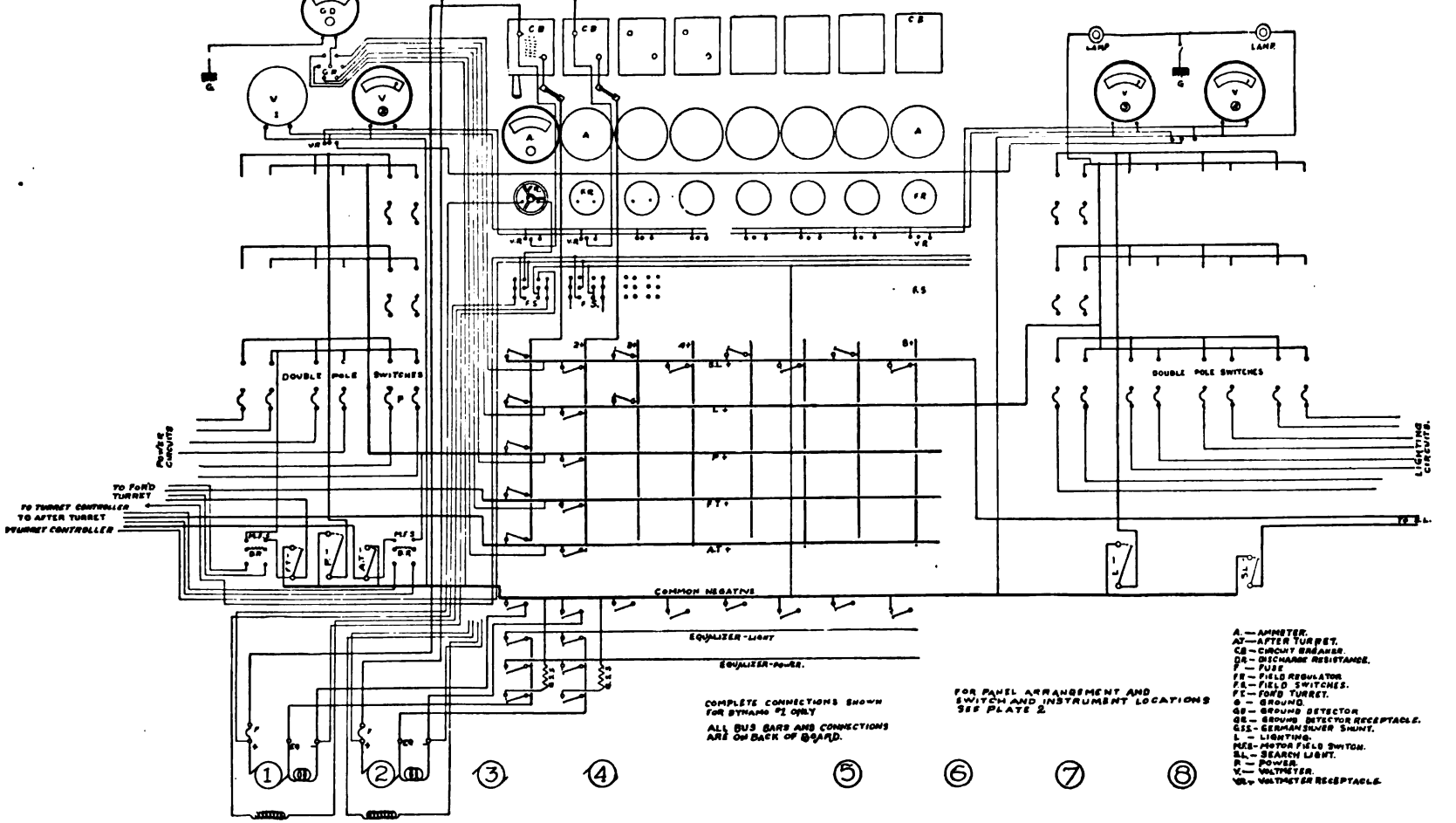


FIG. 269.—Connections of Standard Switchboard.

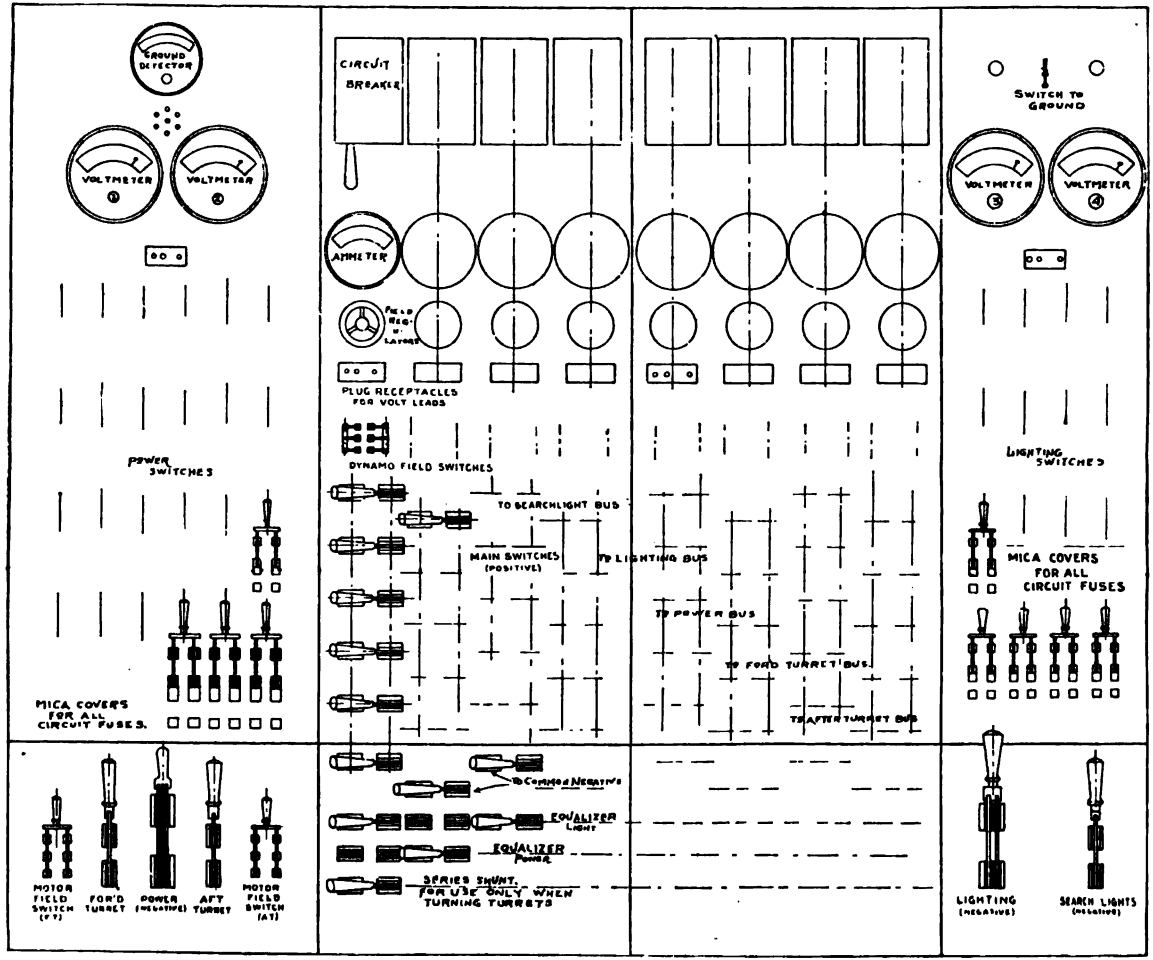


Fig. 270.—Standard Switchboard. Front View.

single-pole single-throw switches controlling the negative legs of the turret-turning circuits, the left-hand switch is for forward turret and the right-hand switch for after turret. Again, outside of these last-mentioned switches are the field switches of the turret-turning motors and generator used for turret turning. These are double-pole single-throw switches with an extra set of long switch clips, across which is connected a field discharge resistance.

To the right of the generator panels is the lighting distribution panel containing as many double-pole single-throw fused switches as may be required. At the top of this panel is an ordinary lamp ground detector, with a small single-pole single-throw switch to break the ground connection (this operation being necessary before using detector on power panel). This panel also contains two voltmeters with plug receptacle underneath. On lower panel are two single-pole single-throw main negative switches, one for lighting circuit and the other for search-light circuit.

Each generator contains on its headboard a main fuse on the positive leg.

All switches on generator panels are to throw horizontally, to be hinged on the *generator* end and throw to the left. For the forward turret, after turret, equalizers and series shunt, removable blade plug switches are to be used.

Only four blades are supplied for each equalizer, and *not more than two blades* for each of the others, *i. e.*, forward turret, after turret and series shunt. When a switch is open, the clip is to be plugged with a stop which will prevent accidental closing.

The field-control switches allow three methods of field excitation. By throwing the two upper switches the machine is made self-exciting. By throwing the two middle switches the machine is separately excited and controlled from the forward turret. By throwing the two lower switches the machine is separately excited and controlled from the after turret.

Voltmeter Connections.—The voltmeter connections, as shown in Fig. 271, are identical with but more clearly shown than in Fig. 270. The plug receptacle on the power circuit panel and the four receptacles on the left-hand generator panel, *i. e.*, for machines Nos. 1, 2, 3 and 4, have a spacing of 1 and 2 inches, whereas the

receptacle on the lighting panel and those for machines Nos. 5, 6, 7 and 8, have a spacing of 1½ and 2½ inches. By using the 1-inch plug on any receptacle on the generator panel the voltage of the machine is read on voltmeter No. 1, likewise by using 2-inch plug the voltage can be read on voltmeter No. 2. Similarly, on the right-hand generator panel the 1½-inch plug throws voltmeter No. 3 across the generator terminals and the 2½-inch plug throws voltmeter No. 4

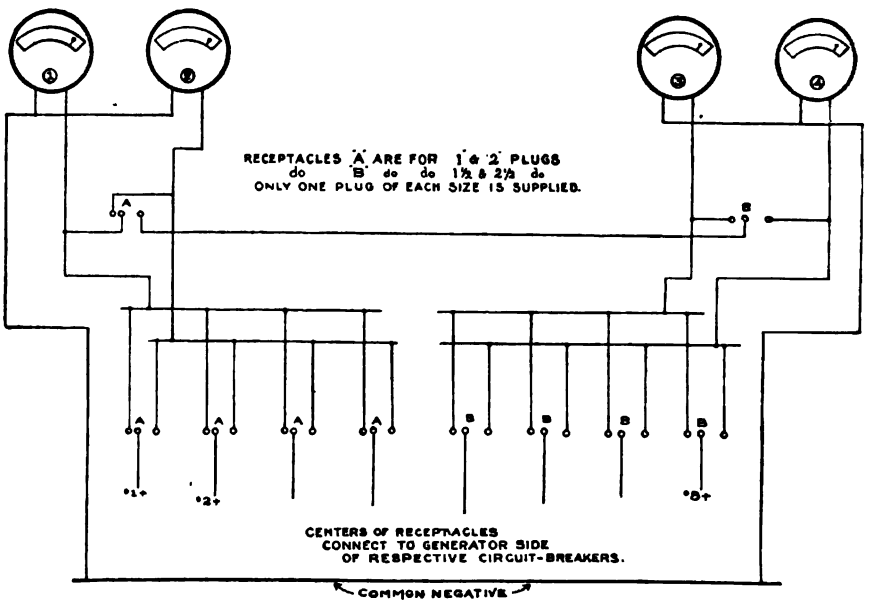

RECEPTACLES 'A' ARE FOR 1 & 2 PLUGS
do 'B' do do 1½ & 2½ do
ONLY ONE PLUG OF EACH SIZE IS SUPPLIED.
CENTERS OF RECEPTACLES
CONNECT TO GENERATOR SIDE
OF RESPECTIVE CIRCUIT-BREAKERS.
COMMON NEGATIVE

FIG. 271.—Voltmeter Connections on Standard Switchboard.

across the terminals. Thus we can read the voltage of any two machines on the left-hand and of any two machines on the right panel (four machines in all) simultaneously.

With the 2-inch plug in a receptacle on the generator panel and the 1-inch plug in the receptacle on the lower panel, we have voltmeter No. 1 in parallel with voltmeter No. 2 for calibration.

With the 1-inch plug in a receptacle on the generator panel, the 2-inch plug in the receptacle on lower panel, and the 1½-inch plug

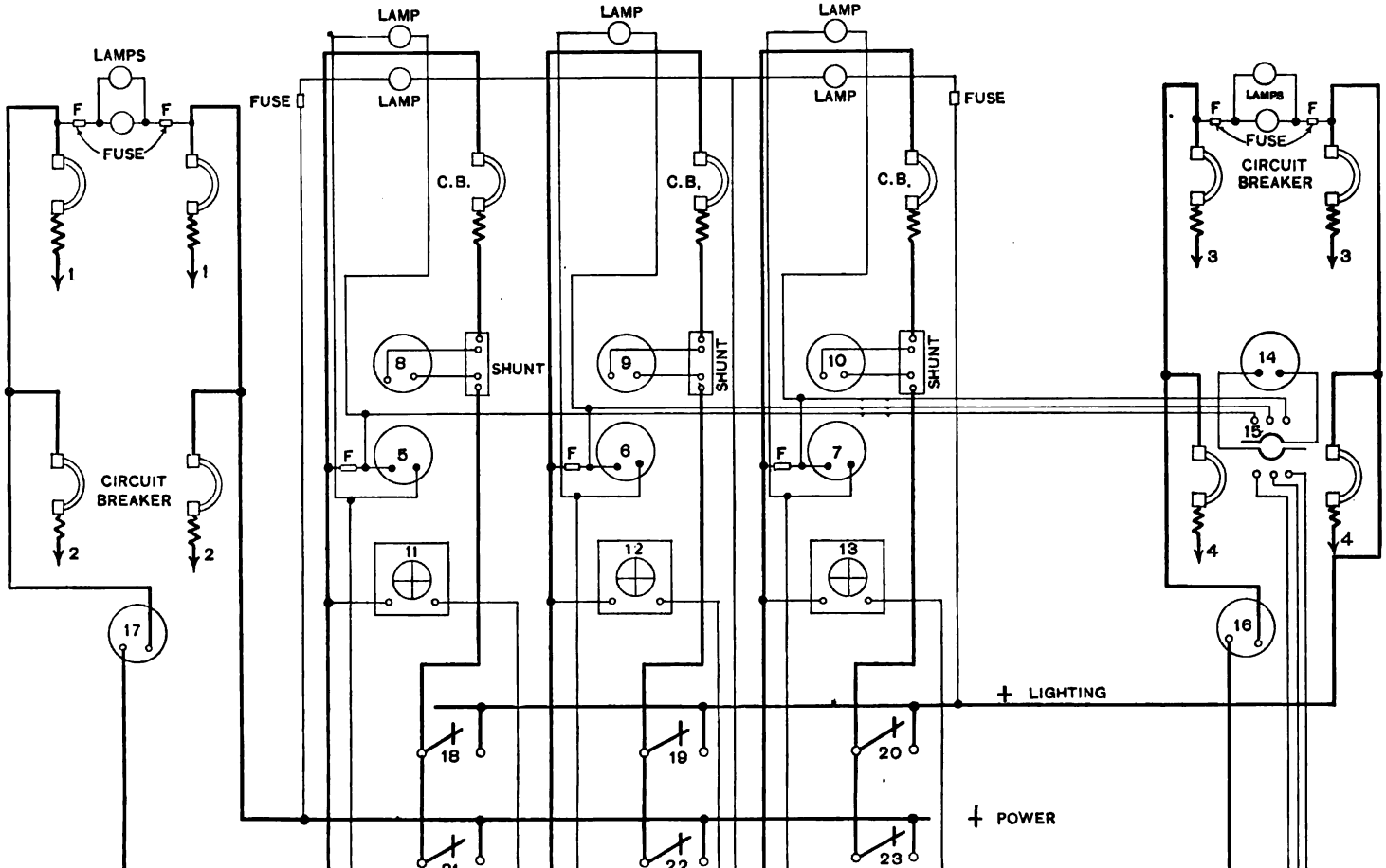
in the receptacle on lighting panel, voltmeter Nos. 1 and 3 are in parallel. By substituting the 2½-inch plug for the 1½-inch plug in the above arrangement Nos. 1 and 4 are in parallel. *As only one plug of each spacing* is furnished, it is impossible to make a short circuit or parallel two machines on the voltmeter connections. An inspection of Fig. 271 shows this to be true.

Parallel Connections.—When starting up a new machine to be parallel with one already running the operation at the switchboard is as follows: 1st, *close circuit breaker;* 2d, *close equalizer switch;* 3d, *close switch to common negative;* 4th, *plug to voltmeter and adjust voltage by field regulator;* 5th, and last, *close positive switch.*

Ground Detectors.—For detecting grounds, the lamp detector on the upper part of lighting panel is connected permanently across the common negative bus and the positive leg on the lighting circuit panel; and when using ground detector on power panel, the ground connection on this lamp detector must be broken. The connections to this ground detector (on power panel) are such that when a circuit is grounded on the positive leg, the instrument will indicate when plugged to negative, and for a ground on the negative of any circuit the instrument will indicate when plugged to any of the positive circuit bus bars, provided of course that said bar is alive, and here it should be noted that a bar is alive when any switch in the horizontal row connecting to it, is thrown.

To locate a ground in the quickest possible manner the group switches, *i. e.,* main negative and positive generator switches on the lighting circuit should be opened; if the ground still appears, these switches should be closed and the corresponding switches on each circuit opened (one circuit at a time) until the ground disappears. When the ground is singled down to one group, the circuit switches on this group should be opened one at a time until the defective circuit is found.

In Fig. 269, the circuits marked lighting circuits, power circuits and search-light may lead to other distribution boards in different parts of the ship, so all the lights or power required for one locality may be controlled independently of the main switchboard. Those marked to forward turret and to after turret lead to panels convenient to those places where are installed the necessary switches and instruments for the proper control of the current.


LAMPS
F
FUSE
F
1
1
CIRCUIT BREAKER
2
2
17
LAMP
LAMP
FUSE
C.B.
8
SHUNT
F
5
11
LAMP
LAMP
C.B.
9
SHUNT
F
6
12
LAMP
LAMP
FUSE
C.B.
10
SHUNT
F
7
13
LAMPS
F
FUSE
F
CIRCUIT BREAKER
3
3
14
15
4
4
16
+ LIGHTING
18
19
20
+ POWER
21
22
23

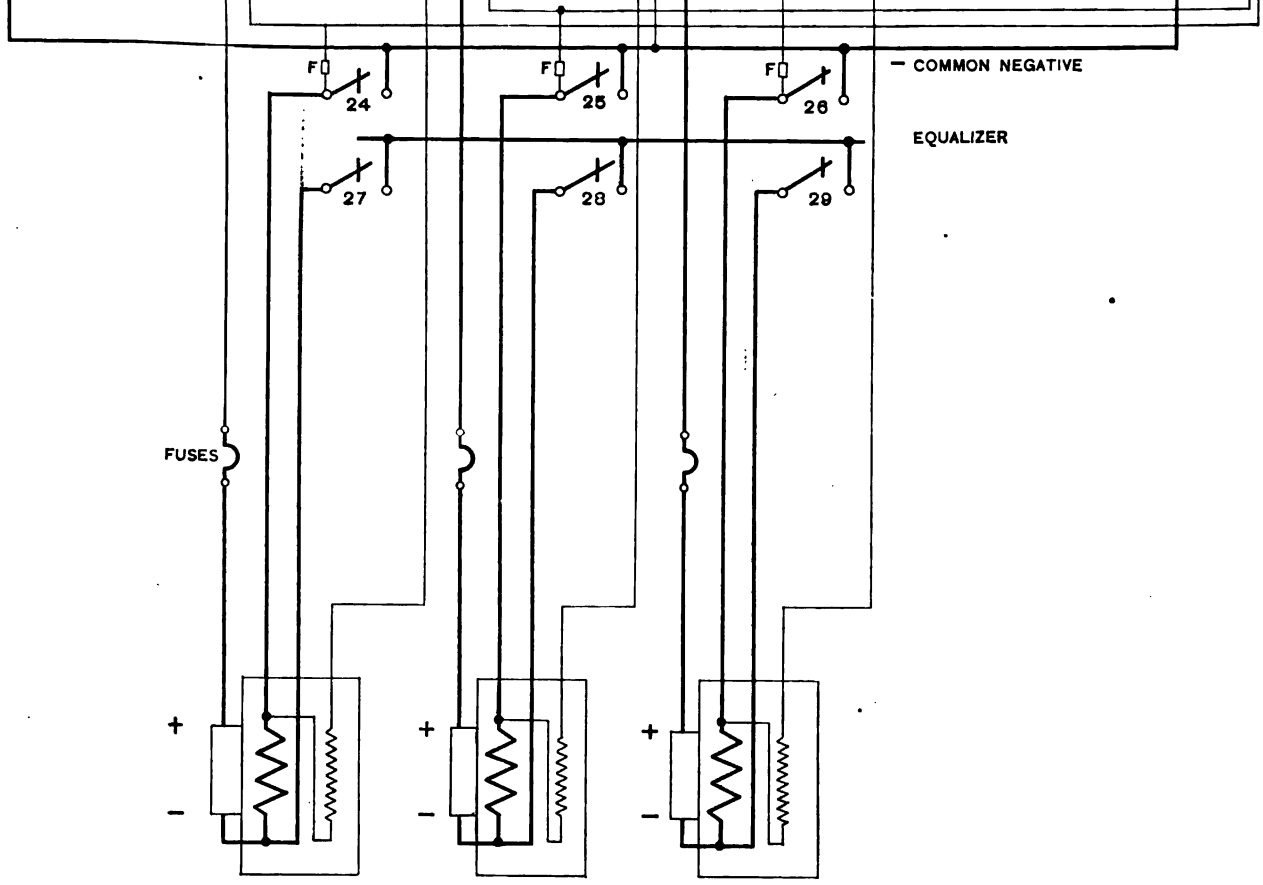


Fig. 272.—Connections of Dynamo Room Switchboard.

Distribution Boards.

Since the adoption of the standard specifications for switchboards given in the preceding sections, other forms of switchboards have been installed to meet the requirements for larger power. In some late ships there are two distinct dynamo-rooms with a dynamo-room board in each room, from which current is distributed to two distribution boards situated in separate parts of the ship. Each dynamo-room can supply each or both of the two distribution boards, and from these latter boards, current is distributed throughout the ship for the various purposes of lighting or power.

The diagrammatic sketches of the dynamo-room board and distribution boards as installed on the *North Carolina* and *Montana* are shown in Figs. 272 and 273.

From the general description of the standard board previously given and with the help of the accompanying list of reference parts, the connections can be easily traced.

Dynamo-Room Board.

1. Power Mains to Starboard Distribution Board.
2. Power Mains to Port Distribution Board.
3. Lighting Mains to Starboard Distribution Board.
4. Lighting Mains to Port Distribution Board.

5, 6, 7. Generator Voltmeters, 150 volts.

8, 9, 10. Generator Ammeters, 1200 amperes.

11, 12, 13. Generator Field Rheostats.

14. Calibrating Voltmeter.
15. Calibrating Voltmeter Switch.
16. Bristol Recording Ammeter, 500 amperes.
17. Bristol Recording Ammeter, 3500 amperes.

18, 19, 20. Positive Lighting Bus Switches.

21, 22, 23. Positive Power Bus Switches.

24, 25, 26. Negative (Common) Bus Switches.

27, 28, 29. Equalizer Switches.

Distribution Boards.

1. Power Mains from Port Dynamo-Room.
2. Power Mains from Starboard Dynamo-Room.
3. Lighting Mains from Port Dynamo-Room.
4. Lighting Mains from Starboard Dynamo-Room.
5. Turret Power Switch from either Starboard or Port Dynamo-Room.
6. Power Switch from either Starboard or Port Dynamo-Room.
7. Lighting Switch from either Starboard or Port Dynamo-Room.

8-8. Double-Pole Circuit Breakers.

9-9. Single-Pole Circuit Breakers.

10. Power Mains to Forward 12-Inch Turret.
11. Power Mains to After 12-Inch Turret.

12-12. Power Mains to 8-Inch Turrets.

13. Power Mains.
14. Search-Light Switches.
15. Ammeter for Total Turret Power.
16. Ammeter for Total Power.
17. Turret and Power Voltmeter.
18. Voltmeter Ground Detector.
19. Lighting Voltmeter.
20. Total Lighting Ammeter.
21. Search-Light Voltmeter.

22, 22, 22. Search-Light Ammeters.

23. Lighting Mains.
24. Turret Lamp Ground Detector.
25. Power Lamp Ground Detector.
26. Turret, Power and Lighting Lamp Ground Detector.
27. Search-Light Rheostats.
28. Search-Light Mains.
29. Voltmeter Ground Detector Switch.

F Fuses.

L Lamps.

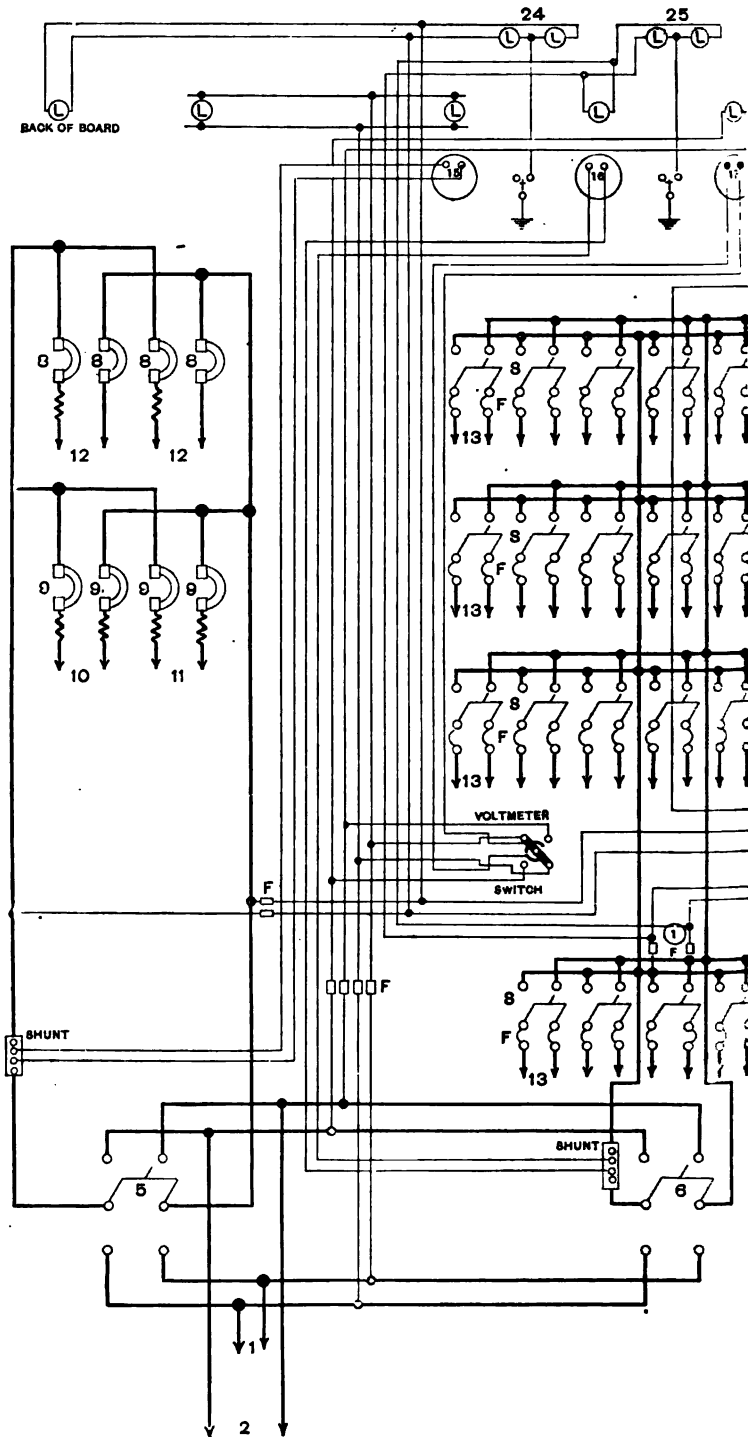
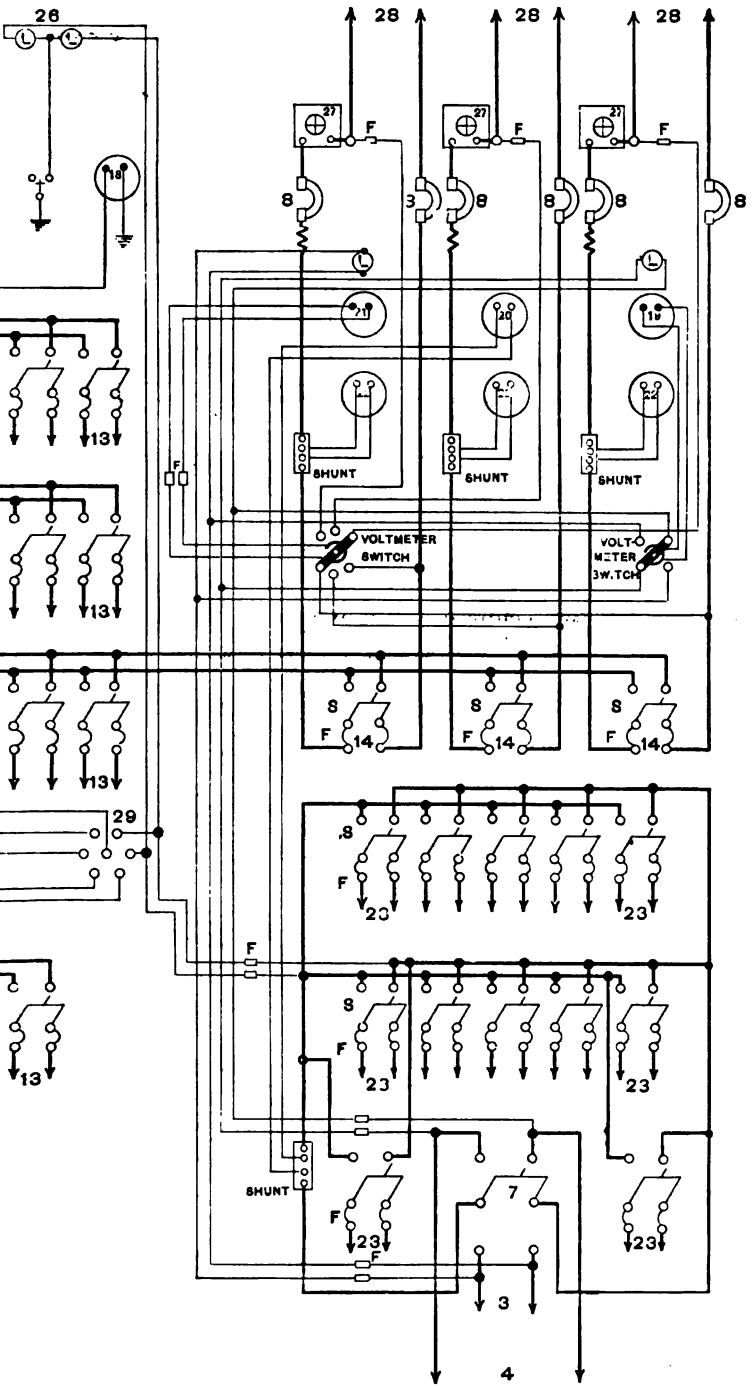

24
25
BACK OF BOARD
8
12
9
10
11
13
F
VOLTMETER
SWITCH
SHUNT
5
6
1
2

FIG. 273.—Conn



tions of Distribution Board.

CHAPTER XXIV.

INCANDESCENT LAMPS.

When a current of electricity is urged through a conductor, heat is developed, the amount of heat being proportional to the amount of energy expended in the conductor. If a current C is forced through a resistance R for a time t, the number of joules, or electrical units of heat developed, is C^2Rt.

The distinction between heat and temperature must be kept in mind. The same amount of heat may be applied to two conductors, and the resulting temperature be widely different. When a conductor is made very hot, or has a high temperature, it becomes luminous and the luminosity is proportional to the temperature. Suppose there were two conductors A and B of same sectional area, and B twice as long as A, and therefore twice its resistance, and equal currents urged through both. The energy expended in A, or the heat developed will be only half that in B, but the temperatures will be equal, as B has twice as much matter as A. The luminosity of these two conductors will be the same, although B absorbs or requires twice as much energy as A. Suppose, however, the conductors are the same length, but B is given the same resistance as before by halving its cross-sectional area. With the same currents as before, B still absorbs twice as much energy as A, and twice as much heat will be developed in B as in A. Since the mass of B is only one-half that of A, equal quantities of heat would cause the temperature of B to be twice that of A, and since twice as much heat is developed in B, its temperature is raised to four times that of A, and therefore its luminosity is four times as great for the same current.

This shows that to obtain great luminosity a large amount of energy must be expended on a small mass of matter, and the mass must be kept small by reducing the area of cross-section rather than by increasing its length and the material should have a high specific resistance. Enough heat may be absorbed by a con-

ductor of small mass to raise its temperature to such a degree that it may become luminous, and if the heat produced by the current is not radiated as fast as produced, the temperature will reach the melting point, and the conductor, or portion of it, will be destroyed by uniting with the oxygen of the air. If the conductor was heated to incandescence before burning up and it could be kept in such a state, then we would have an incandescent lamp.

To prevent its uniting with oxygen, the resistance of an ordinary incandescent lamp is secured in a glass bulb from which almost all air and other gases have been exhausted.

Manufacture of Lamps.

The materials which have been tried in the incandescent or glow lamp are platinum, osmium, iridium, an alloy of platinum and iridum, carbide of titanium, tantalum, tungsten and carbon. Of these, carbon is the substance almost universally employed, its chief advantages being: (1) That after the temperature of incandescence is reached, the luminous rays increase more rapidly than the heat rays for further increases of temperature than is the case with metals. (2) Its temperature of volatilization is higher than that of metals. The temperature at which metals emit light is not much less than their melting points, while carbon has no actual melting point, but a temperature of volatilization higher than that needed for incandescence. (3) The cross-sectional area of carbon can be made more nearly uniform than is possible with metal wires.

The complete manufacture of an incandescent lamp requires from thirty to forty distinct operations, the principal of which are given in the following description:

The **filament** is the chief feature of all glow lamps and upon its manufacture depends the success and behavior of the completed lamp. In nearly all cases, the filament is made from cellulose, a transparent, gelatinous hydrocarbon. This cellulose is prepared in different ways as follows:

1. Treating pure cotton wool to a washing and boiling operation to remove any "dressing," dirt or foreign material obtained in the course of its manufacture. After drying, the wool is wound loosely around two opposite sides of a rectangular glass frame of such a

size that each ply is a little longer than the length of the completed filament. The cotton thus wound is immersed in a clear solution of pure concentrated sulphuric acid and pure water of proportions 2 to 1. This operation only takes a short time and is complete when the last traces of the strands of cotton disappear, after which the frame is immersed in clear running water. It is next immersed in a one per cent solution of ammonia and water to remove all traces of acid and again washed in clear water. The cotton has been transformed into the transparent, gelatinous substance known as cellulose.

2. The purest cotton wool is heated with a solution of zinc chloride in which it dissolves, forming a syrupy mixture from which is precipitated by alcohol a hydrated cellulose zinc oxide. The solution is treated with hydrochloric acid which liberates the zinc, after which it is washed and the solution is reduced to cellulose by ammonium sulphide. The fluid result is a brownish liquid of about the consistency of molasses.

3. Special kinds of paper are chemically treated in such a way as to produce a thick solution of cellulose.

Forming the Filament.—After the thick gelatinous mass of cellulose has been obtained, the desired form of the filament is made while it is still in a pliable condition. The solution is forced by light pneumatic pressure through orifices or dies, made of sapphire-agate stones which contain holes of diameters corresponding to the area of cross-section desired. The cellulose issues from these holes in a continuous thread and is allowed to coil in glass jars filled with alcohol which acts to set and harden it. This thread is allowed to remain until all traces of the zinc chloride disappear when the thread now resembles fine cut catgut and is tough and flexible. It is washed well to remove all traces of chemicals and is then ready for shaping.

The filaments are **shaped** by winding the thread over "formers" of carbon, according to the desired shape of the completed filament. These are then lightly baked to ensure the shape being retained. Such a shape is shown in 2, Fig. 274.

Carbonizing the Filament.—After forming, the thread is removed from the formers and is closely packed with powdered carbon

in graphite crucibles. These crucibles are then placed in a coke furnace and brought gradually to a white heat, at which temperature they are kept for a day or two when they are allowed to slowly cool. This operation converts the threads into pure carbon of a dull black color. The threads are then measured for diameter by micrometer calipers, measuring to $\frac{1}{10000}$ inch and sorted according to diameters.

The next step in the process of manufacture is the **flashing** process, and the arrangement for doing this varies in different factories. In general it consists in raising the filament to a high degree of incandescence while it is an atmosphere of some hydrocarbon vapor such as gasoline or benzine. The thinner portions of the filament become hotter than the rest which causes the carbon in the vapor to be deposited in greater quantity at those points, as well as in every little hole in the filament, and thus causing the filament to become of uniform cross-section throughout.

In some processes, the filament is hung in an air-tight vessel containing the hydrocarbon, which vaporizes and surrounds the filament; in others, the vessel is fitted with two orifices, by which air may be exhausted from one and vapor admitted at the other. This method insures the rapid volatilization of the liquid hydrocarbon. While surrounded by the vapor, the filament is connected either to a generator or a storage battery and heated to incandescence, the operation being repeated several times. As the carbon is deposited the resistance decreases and the current increases, and automatic arrangements are made by which the current is shut off when the desired resistance has been attained.

The color of the filament has now changed to a steel gray and is coated uniformly with finely divided, hard and compact carbon. It is now ready for connection to the plug.

Small copper wires, such as shown in 1, Fig. 274, are attached to two platinum wires, each about $\frac{1}{2}$ inch in length, by heating and fusing the two together. This combination of wires is then assembled in a glass tube (3, Fig. 274), the platinum wires being fused in the glass (4, Fig. 274). Platinum is used because it does not fuse at the temperature necessary for fusing the glass, and its coefficient of expansion is about that of glass, so there is no

danger of leakage of air into the exhausted bulb due to unequal expansion.

The filaments are then attached to the platinum wires by a carbon paste or cement which is carbonized by passing a current through the filament. The completed filament is shown at 5, Fig. 274, and is then ready for attachment to the glass bulb.

The Bulb.—There are no peculiarities in the construction of the bulbs, which are blown to the proper size and shape (7, Fig. 274).

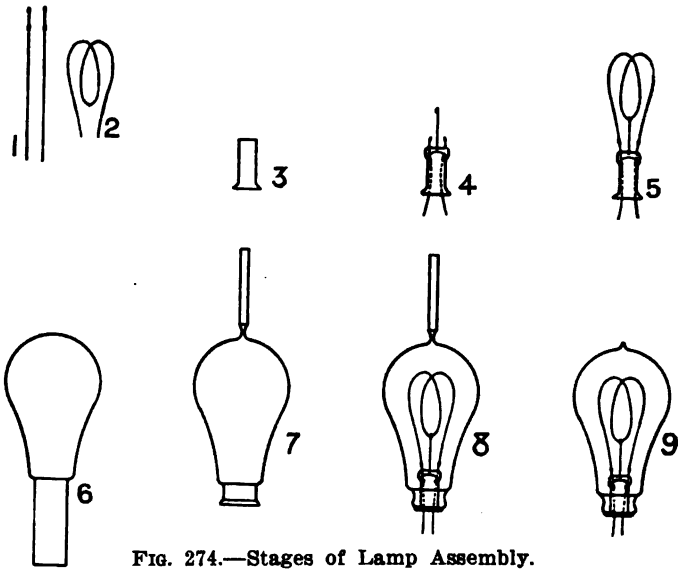


FIG. 274.—Stages of Lamp Assembly.

The glass tube holding the filament is secured in the mouth of the bulb and the edges are fused to the edge of the bulb (8, Fig. 274).

Exhausting the Lamp Bulb.—It is of the utmost importance to secure a good vacuum inside the bulb, for the efficiency as well as the life of a lamp depends upon the goodness of the vacuum. The poorer the vacuum the greater the conduction of heat from the filament to the bulb and to the outside atmosphere, so that the energy absorbed by the filament is not given as temperature to the filament and the efficiency is reduced.

The life is shortened due to the disintegration of the filament

which is made manifest by the blackening of the inside of the bulb by the deposition of carbon on it.

The bulb is connected to an air-suction pump, as the Sprengel mercurial pump. When the vacuum has attained a steady value, current is sent through the filament so as to heat it to redness and gradually increased to about 25 per cent above the normal incandescence. This drives out any air that may be held in the filament, the pump kept going all the time. When the desired vacuum has been attained, the glass tube blown in the bulb and by which it is connected to the tube leading to the pump is gradually heated near the bulb until the glass softens. The bulb is gradually pulled away and the softened glass of the tube draws together and gradually closes the opening and a final twisting motion seals the bulb leaving the little sharp nipple seen on all glow lamps. The lamp as now completed is shown in 9, Fig. 274.

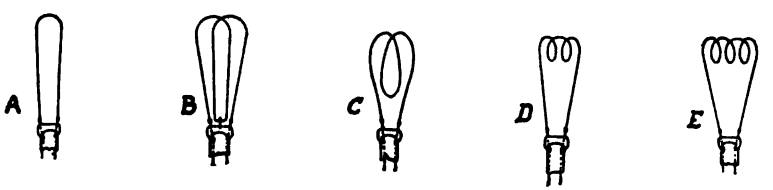


FIG. 275.—Types of Filaments.

The Base Attachment.—The standard Edison base consists of a threaded brass open-ended cylinder, perforated with a hole near the middle of its length, and of a brass disc perforated through its center. The copper leading-in wires of the completed combination shown in 9, Fig. 274, are threaded through the holes, one in the cylinder and one in the disc. The whole cylinder is then filled with plaster of paris and when this sets, the ends of the wires are trimmed off and soldered at the perforations.

In a method using a glass plug in place of plaster of paris, the plug is made of molten glass poured in the base, after which the contact is secured by a rivet. The other leading wire is soldered at the top of the base.

The types of filaments used in naval incandescent lamps are shown in Fig. 275, and the lamps with which they are used are given in the table on page 588.

Candle-Power of Incandescent Lamps.

Lamps are rated and marked at so many candle-power, the standard now used in the service being 1, 2, 5, 6, 10, 16, 32 and 150 candle-power. For ordinary illumination 16-candle-power lamps are used, those of 5 candle-power being used in store-rooms and passages below decks, those of 32 candle-power in the night signal system, running lights, truck lights and anchor lights, and those of 150 candle-power for general illumination in open spaces, where a large amount of light is needed for night purposes and in the diving lamp—these generally being used in portable fixtures. Lamps of 1, 2, 5 and 10 candle-power are used in instruments and telephotos, and the 6 candle-power for torpedo lamps.

Standard Lamp.—A 16-candle-power lamp is one that will give the same intensity of light, or the same amount per unit of area as sixteen standard candles, or an intensity sixteen times as great as one standard candle; a standard candle being a spermacetic candle $\frac{7}{8}$ of an inch in diameter, burning 120 grains per hour. The practical unit of white light is the quantity of light emitted normally by a square centimetre of surface of molten platinum at the temperature of solidification.

Comparison of Lights.—Incandescent lamps are compared with a standard candle by means of photometers, these being instruments by which the amount of light falling on a given surface may be measured, or by which the effect of light from two sources is neutralized, and the intensities of the two lights compared. The intensity of light from a given source is determined by the physical law, *that the intensity of light received by an object varies inversely as the square of its distance from the source of light.*

All lamps have marked on them the voltage necessary to produce the rated candle-power. A lot of lamps made at the same time, by the same process and by the same workmen with the same care will not all give the same candle-power for the same voltage. Instead of considering the voltage constant and determining the candle-power, the candle-power is regarded constant, and the voltage necessary to produce that candle-power is determined and marked on the lamp. Lamps are tested for candle-power in connection with the photometer in a horizontal position, that is, the

lamps themselves hang vertically with the loop of the filament opposite and on a level with the spot on the photometer to be illuminated, and the candle-power thus obtained is called the *horizontal candle-power*. As the candle-power thus obtained would be different from that determined in any other position, it is necessary to find what is called the mean or average spherical intensity of the illumination.

The **mean spherical candle-power** is the average candle-power on the interior surface of a sphere, of which the source of light is the center.

Effect of Age on Candle-Power.—When a lamp is first connected to a circuit, the candle-power increases for a time and then begins to fall, reaching the initial candle-power at the end of about 100 hours' burning, and the decrease in candle-power is steady from that time. As the efficiency rises, the candle-power falls more rapidly. A lamp absorbing 3.5 watts per candle-power will fall to about 75 per cent of its candle-power at the end of 900 hours, and one absorbing 2.5 watts will fall to the same percentage at the end of about 300 hours.

As a lamp gets old and its candle-power and efficiency fall, it is much better after a certain point to throw it away than to continue to burn it till rupture takes place.

Over and Under Running.

As far as possible all lamps should be worked at the voltage which will give their rated candle-power. The voltage that a lamp will require is determined by the dimensions of the filament, and each filament is so constructed as to yield its standard candle-power at the highest temperature, about 2000° C., compatible with durability, and much increase of temperature would probably cause rupture of the filament. A very slight increase in the voltage produces a much greater per cent increase in luminosity, but a corresponding danger of rupture. The candle-power increases much faster than the voltage and experiments seem to show that the candle-power of a given lamp varies as the sixth power of the applied voltage or as the cube of the absorbed watts. When the candle-power is reduced one-half the power absorbed in the filament has only fallen about 20 per cent.

This consideration shows that by under running a generator, that is running at a lower speed and consequently at a lower voltage than the normal, no advantage is gained. Even a reduction of 2 per cent in the normal voltage makes itself very apparent in the amount of light emitted, and while it may act to prolong the life of a lamp the effect is neutralized by the reduced efficiency, more power being required to produce the candle-power as the voltage falls.

The effect of over running is to seriously lessen the life of lamps, an increase of 3 per cent in the voltage being sufficient to reduce the life of a lamp to one-half, and an increase of 6 per cent to one-third.

Efficiency of Incandescent Lamps.

The efficiency of a lamp is the ratio of the mean spherical candle-power to the electrical power absorbed in producing it, but is usually referred to as so many watts per candle-power. If a 16-candle-power lamp absorbed 56 watts, its efficiency would be spoken of as 3.5 watts, that is 56 ÷ 16, its efficiency being $\frac{16}{56} = .286$. The electrical power absorbed is obtained by properly connecting up an ammeter and voltmeter in the lamp circuit when testing it for candle-power in the photometer, the product of the volts and amperes giving the total watts absorbed. The electrical horse-power spent on a lamp is equal to the number of watts absorbed by the lamp divided by 746. The number of heat units or calories given out per candle-power is found by multiplying the number of watts absorbed by .24 and dividing by the number of candle-power.

The question of efficiency is closely connected with the candle-power and life of a lamp. High efficiency means high voltage, high candle-power and high temperature and consequent economy but at the expense of short life, while a reduced efficiency means less economy and longer life. A lamp that is burning at a reduced candle-power yields a lower efficiency but lasts longer than one of the same type at the full power, but it is more economical to run lamps at a high than at a low efficiency. The average life of initially high efficiency lamps is short and they deteriorate rapidly in candle-power and efficiency after about 200 hours' burning.

Standard Incandescent Lamps.

The lamps manufactured for the use of the Naval Service must conform in dimensions and shapes to certain standards, these being shown in Fig. 276.

The bases for the 100, 32, 16 and 10 candle-power are of the standard form Edison base, that for the 5 candle-power is of the

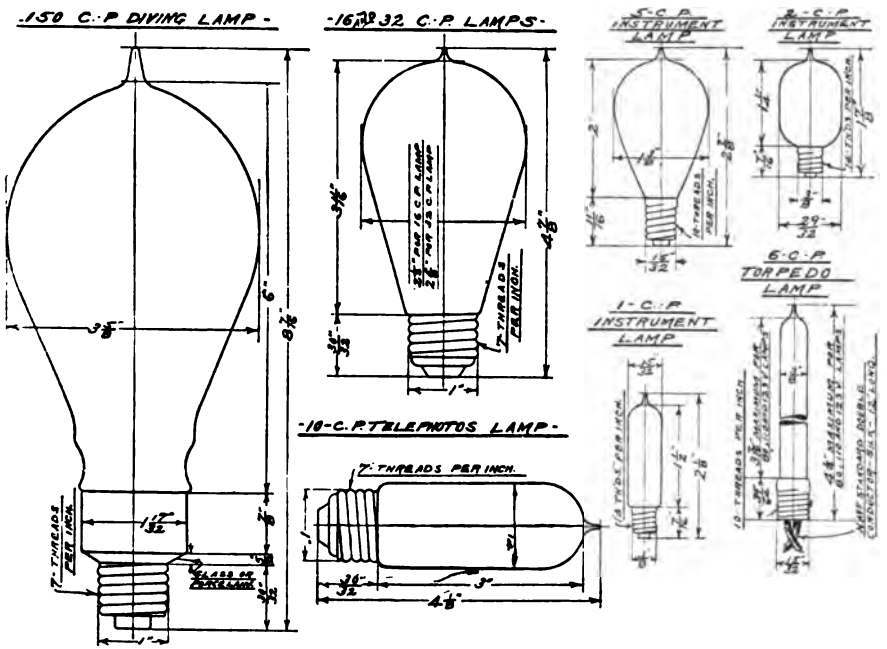


FIG. 276.—Standard Lamp Shapes.

candelabra form of Edison base. The base of the 6-candle-power torpedo lamp is fitted with leads as shown in the figure.

The bases are fitted with porcelain or glass buttons, forming the insulation between the contacts. These buttons are designed so that it is only necessary to make one channel through the button and this passes through the center of the button for the purpose of permitting the attachment of one of the leading-in wires to the contact in the center of the base. The base is firmly and accurately

fitted to the bulb with moisture proof cement. The leading-in wires and anchors are fused in the glass. These last are metal pieces secured to the loop to strengthen it and to prevent the loop from drooping when used in a horizontal position.

The filaments are centered in the bulb and in the case of the 32, 16 and 10-candle-power telephotos and 6-candle-power torpedo lamps are anchored.

Each lamp is marked to the nearest even volt that is necessary to give its rated candle-power.

1	2	3	4	5	6	7	8	9
Class.	Rated candle-power.	Standard total watts.	Type of filament.	Individual voltage limits.	Individual total watt limits.	Candle hour area at rated efficiency.	Candle hour area at 3.1 W. P. C.	Test candle-power to give 3.1 W. P. C.
SPECIAL LAMPS.								
Instrument.								
1 c.-p., 10 volts, clear.....	1	4.9	Loop.....	9.25-10.75	4.5- 5.8	552	68	2.02
2 c.-p., 80 volts, clear.....	2	11	Double loop	78- 84	10.1-11.9	1,288	92	4.79
2 c.-p., 110 volts, clear....	2	13	8-coil spiral	106-116	12-14	1,472	55	6.1
2 c.-p., 223 volts, clear....	2	13	....do.....	119-129	12-14	1,472	55	6.1
Torpedo.								
6 c.-p., 80 volts, clear.....	6	30	Loop.....	77- 85	27-33	138	15.4	12.5
6 c.-p., 110 volts, clear....	6	30	....do.....	106-116	27-33	138	15.5	12.5
6 c.-p., 123 volts, clear....	6	30	....do.....	119-129	27-33	138	15.4	12.5
Telephotos.								
10 c.-p., 80 volts, clear....	10	36	Oval.....	75- 83	34-38	3,680	1,840	12.5
10 c.-p., 110 volts, clear...	10	36	....do.....	104-112	34-38	3,680	1,840	12.5
10 c.-p., 123 volts, clear...	10	36	....do.....	119-127	34-38	3,680	1,840	12.5
REGULAR LAMPS.								
Regular.								
5 c.-p., 80 volts, clear.....	5	19.5	2-coil spiral	77- 83	18-21	2,760	920	7.14
5 c.-p., 110 volts, clear....	5	19.5	....do.....	105-113	18-21	1,150	368	7.14
5 c.-p., 123 volts, clear....	5	19.5	....do.....	119-127	18-21	1,150	368	7.14
16 c.-p., 80 volts, clear....	16	56	Oval.....	77- 82	53.2-58.8	12,000	8,000	19
16 c.-p., 80 volts, frosted..	16	56	....do.....	78- 83	53.2-59.8	12,000	8,000	19
16 c.-p., 110 volts, clear....	16	56	....do.....	107-112	53.2-58.8	12,000	8,000	19
16 c.-p., 110 volts, frosted.	16	56	....do.....	108-113	53.2-59.8	12,000	8,000	19
16 c.-p., 123 volts, clear....	16	56	....do.....	121-125	53.2-58.8	12,000	8,000	19
16 c.-p., 123 volts, frosted.	16	56	....do.....	122-126	53.2-59.8	12,000	8,000	19
32 c.-p., 80 volts, clear	32	115	....do.....	76- 82	109 121	20,000	11,000	40
32 c.-p., 110 volts, clear ...	32	115	....do.....	106-112	109-121	20,000	11,000	40
32 c.-p., 123 volts, clear ...	32	115	....do.....	120-126	109-121	20,000	11,000	40
Diving.								
150 c.-p., 80 volts, clear ...	150	465	2-coil spiral	76- 82	442-488	18,800	18,800	150
150 c.-p., 110 volts, clear ..	150	465	2 loop.....	106-112	442-488	20,700	20,700	150
150 c.-p., 123 volts, clear ..	150	465	...do.....	120-126	442-488	20,700	20,700	150

VALUES FOR NAVY SPECIAL LAMPS.

Description of lamp.		Rating.		Initial limits.		Average performance.
Class.	Type of filament.	Rated candle-power, mean horizontal.	Initial total watts.	Individual candle-power limits.	Individual watts limits.	Useful or effective life in hours to 20 per cent drop in candle-power at 3.1 watts per candle.
Torpedo.						
6 c.-p., 80 volts	Loop	6	30	33⅓ per cent above and 33⅓ per cent below.	25 per cent above and 25 per cent below.	1
6 c.-p., 110 volts	do.	6	30	do.	do.	1
6 c.-p., 123 volts	do.	6	30	do.	do.	1
Telephotos.						
10 c.-p., 80 volts clear	Oval	10	36	25 per cent above and 25 per cent below.	17 per cent above and 17 per cent below.	160
10 c.-p., 110 volts clear	do.	10	36	do.	do.	160
10 c.-p., 123 volts clear	do.	10	36	do.	do.	160
Regular Navy instrument.						
5 c.-p., 80 volts	2-coil spiral.	5	19.5	30 per cent above and 30 per cent below.	25 per cent above and 25 per cent below.	150
5 c.-p., 110 volts	do.	5	19.5	20 per cent below and 20 per cent above.	15 per cent below and 15 per cent above.	100
5 c.-p., 123 volts	do.	5	19.5	25 per cent below and 25 per cent above.	20 per cent below and 25 per cent above.	70
Regular.						
16 c.-p., 80 volts	Oval	16	56	25 per cent above and 25 per cent below.	17 per cent above and 17 per cent below.	450
32 c.-p., 80 volts	do.	32	115	do.	do.	300
32 c.-p., 110 volts	do.	32	115	do.	do.	300
32 c.-p., 123 volts	do.	32	115	do.	do.	300
Diving.						
100 c.-p., 80 volts	Double loop.	100	250	30 per cent above and 30 per cent below.	25 per cent above and 25 per cent below.	
100 c.-p., 110 volts	do.	100	250	do.	do.	
100 c.-p., 123 volts	do.	100	250	do.	do.	

Tests.

Lamps are tested for the purpose of determining the initial voltage, the total watts expended at the rated candle-power, the physical characteristics of the lamps and for life. The requirements as to electrical qualifications are given in the table on page 589.

Physical tests require an examination of the bases, filaments and the vacuum; loose bases, spotted or discolored filaments or a poor vacuum being sufficient to reject them.

From each quantity of lamps submitted for test, 10 per cent, known as the test quantity, shall be selected at random for test for the purpose of determining the mechanical and physical characteristics of the lamp, the individual limits of candle-power and watts per lamp and the life and candle-power.

If 10 per cent of the test quantity show any physical defects, the entire lot may be rejected without further test.

When tested at rated voltage, the test lamps shall not exceed the limits given in the schedule. If 10 per cent of the test lamps is found to fall beyond the limits stated, the entire lot may be rejected without further test.

Unit of Candle-Power.—The unit of candle-power is the candle as determined by the Bureau of Standards at Washington, D. C.

Photometric Measure.—The basis of comparison of all lamps is the same spherical candle-power. The nominal candle-power is the mean horizontal candle-power of lamps having a mean spherical candle-power value of 82.5 per cent of the mean horizontal candle-power. This is the standard value for filaments of the oval anchored type, other type filaments having a different percentage value.

Life and Candle-Power Maintenance.—Life tests are made as follows: From each accepted package of lamps two sample lamps are selected which approximate most closely to the average of the *test quantity.* One of the two lamps thus selected will be subjected to a life test and designated as the *life test lamp,* the second or duplicate lamp being reserved to replace this *test lamp* in case of accidental breakage or damage during the life test. *The test lamps* are operated for candle-power performance at constant poten-

tial, average variations of voltage not to exceed one-fourth of 1 per cent, either side. The voltage for each lamp shall be that corresponding to an initial specific consumption of 3.76 watts per mean spherical candle, or, if tested upon a different basis, the results shall be corrected to a basis of 3.76 watts per mean spherical candle.

Readings for candle-power and wattage are taken during life at the marked voltage of the lamps at approximately 50 hours, and at least every 100 hours afterwards until the candle-power shall have fallen 20 per cent below the initial candle-power, or until the lamp breaks, if within that period. The number of hours the lamp burns until the candle-power has decreased to 80 per cent of its initial value, or until the lamp breaks, is known as the useful or effective life.

The average candle-power of lamps during life shall not be less than 91 per cent of their initial candle-power. In computing the results of test of a lot of lamps the average candle-power during life shall be taken as the arithmetical mean of the values for the individual lamps of the lot tested.

Accurate recording voltmeter records are obtained during the test on lamps to show the average variation on the circuit.

When so tested the lamps shall average at least the values for useful life given in the table.

Illumination.

Illumination is the amount of light falling upon some unit of area, as a square foot, of the surface to be lighted and is independent of the nature of the surface, and the light may be either reflected, absorbed or transmitted. The illumination depends upon (1) the quantity of light from the source and (2) the distance between the body illuminated and the source. The unit of illumination generally accepted is the *candle foot,* being that amount of light falling upon a body at a distance of one foot from a standard candle. The intensity or amount of light per unit area also varies inversely as the square of the distance from the source of light. The question of the kind and location of incandescent lamps for ordinary ship's illumination is one that presents few difficulties, but one that creates at times considerable criticism. One candle

foot is a convenient illumination for reading. For the ordinary heights on shipboard, one 16-candle-power lamp will illuminate well about 50 square feet of surface. As a matter of efficiency, pure and simple, that is to get the greatest amount of light from a given power, it would appear that all lamps installed should have naked, clear glass bulbs; but other questions than efficiency, especially on shipboard arise, such as personal taste, structural details and the effect on the eye in reading, writing or working.

For lighting in cabins and state-rooms, it is usual to use frosted globes, these being necessary for comfort and appearance even though some of them absorb even as much as 60 per cent of the light emitted. This loss of light seems a great waste, but not as much perhaps, as would seem on first glance. The filament in a frosted globe is invisible and the whole bulb looks as though it were the source of light, and the luminous area being thus enlarged, there is less contrast between the source of light and the objects lighted. In reality, the frosted globe is a better dispenser of light than the clear globe, each little particle of the rough glass acting as a prism, refracting the rays in all directions. A room with a naked gas flame appears poorly lighted compared to the same flame surrounded by a globe although the light emitted is certainly less in the latter case. It is often a question whether for reading or desk work a clear bulb high up or a frosted one low down will give the best results; the amount of light received being not far from the same in both cases; the clear one losing in intensity due to its distance away. It seems perfectly proper not to use clear globes when they come within direct and constant range of the eye, as the pupil of the eye will involuntarily contract at the dazzling light, and it is doubtful if more rays actually enter the eye than in case of the frosted globe.

Overhead lighting seems to be best adapted for ships' use for standing lights in open spaces where men are not berthed and side lighting where they are. In store-rooms and passageways, it is usual to place the lights where they are least in the way of movables, general illumination only being required.

Simply as a matter of illumination and uniform distribution of light, a small number of low candle-power lamps is better than one

lamp of the combined candle-power, thus four 16-candle-power lamps would give a better general effect than two 32's, although no more power is absorbed.

The question of color of sides or ceiling of a room has considerable to do with the lighting effect. Dull and dark surfaces absorb as much as 80 per cent of the light incident on them, while clean, white surfaces will reflect that much, adding to the general effect. With fairly white walls, a rule which allows two watts for every square foot of floor area, is one that would give more than ample illumination.

Tantalum and Tungsten Filaments.

The conductivity of metals is very much higher than that of carbon and several varieties of metal filaments have been used in lamps of recent manufacture. Owing to the high conductivity, the use of a long wire of small diameter is necessary and a filament of tantalum presents the unusual appearance shown in Fig. 277. With ductile metals as tantalum such a filament is comparatively easy to make, but with non-ductile metals like tungsten, the method is not so simple.

FIG. 277. The Tantalum Filament Incandescent Lamp.

To make a tungsten filament, a carbon filament is first made which is electroplated with metallic tungsten. This is then *flashed* in an atmosphere of hydrogen at very high temperature which results in the absorption of the tungsten by the filament and the production of carbide of tungsten. The carbon is removed by heating the filament to a high temperature while it is surrounded with tungsten oxide. The carbon oxidizes and passes off leaving the metallic tungsten filament.

The Nernst Lamp.

Although the Nernst lamp has not been used in the naval service, it is of interest on account of the principles involved in its construction and of the high efficiencies obtained.

This lamp differs from the ordinary incandescent lamp in that it is not enclosed in a vacuum, and instead of the filament being made of carbon, it is made of some highly refractory oxides "rare earths," such as zirconia, thoria or yttria, made in the form of little rods and mounted on platinum wires by means of a paste of the refractory oxides. The lamp is operated in air and is only protected by the very high melting point of the filament. This filament is a non-conductor when cold but becomes a conductor when heated and its resistance decreases as the temperature increases. This is corrected by a steadying resistance in series with the filament, and including this resistance, the efficiency varies from .8 to 1.8 watts per candle-power. The steadying resistance is enclosed in a glass tube from which the air has been exhausted to protect the wire from oxidation.

In order to make it conducting, the temperature is raised by what is called a *heating resistance* in shunt with the filament and close to it. The heater consists of one or more clay tubes wound with high resistance and covered by fire-clay. When the filament commences to conduct, a cutout disconnects the heater.

This lamp finds its greatest application for outside illumination, though with frosted globes it is very satisfying for large interior spaces.

CHAPTER XXV.

ARC LIGHTS.

The arc light is the oldest form of electric light known. Until recently it found no practical use for lighting on shipboard but now it is used in large spaces for general illumination as in the engine-rooms of large modern vessels. The application of the arc light to the focus of a reflecting minor, spherical or parabolic, in an enclosure to give a beam of reflected light gives the search-light.

General Principles.—If two carbon points, forming part of a closed circuit in which a current is flowing, be separated a short distance and the current is strong enough, a spark will jump from one to the other. If the current continues steady and strong enough, a series of sparks will continue to jump from one to the other and if the distance between them is not too great, a flame will soon form, and this flame gives out light and heat. The explanation is as follows: The current passing from one carbon to the other is suddenly arrested when the carbons are separated, or more properly speaking, the current meets with a greater resistance, that of the air between the points, and the first spark is due to the high E. M. F. of the momentarily self-induced current. The current continues to flow through this high resistance, the result of which in a short time is to heat it; that is the air gap, to such a degree that it becomes incandescent.

The incandescent flame produced between the points of the carbons has a violet appearance, and from the fact that the original source of E. M. F. was a voltaic battery, it is commonly called the "voltaic arc." The word arc is a corruption of "arch," which was originally used to designate the shape of the flame.

Production of the Arc.—The operation of producing an arc by first bringing the carbons in contact and then separating them is commonly known as "striking the arc." The reason for this pre-

liminary contact is that it would require a much greater E. M. F. in the circuit to start an arc across even the thinnest filament of air between the carbons. When the carbons first touch and current flows between them, the junction gets very hot owing to the resistance of the imperfect contact and when separated, the heat volatilizes some of the carbon and lowers the resistance sufficiently to allow the current to continue to flow.

Electrodes.—The choice of electrodes used with the arc is practically limited to carbon in some form or other. The intensity of light depends on the temperature at which volatilization takes place, and most metals have a low temperature of volatilization compared with carbon, and their temperatures of incandescence are very near their melting points. Carbon cannot be melted into a liquid state, but passes direct from the solid into the gaseous state, or volatilizes, only at a very high temperature.

Form and Temperature of Arc.—The result of the great heat formed in the arc is to heat the carbon the current leaves, the positive carbon, and this heat produces a carbon vapor that is projected across to the negative carbon. The vapor helps to form a conductor for the current and becomes incandescent. This incandescent vapor is not the chief source of light, for solids are better radiators than gases, and the carbon tips are much hotter than the vapor. The temperature is so high that the positive carbon actually boils, and this glowing portion is the chief source of light.

The vaporization goes on most intensely in the center of the positive carbon, lessening as the distance is increased from the center, and this burns a hollow-shaped cavity in the positive carbon forming what is known as the **crater.** This crater is the source of most of the heat and light, very little coming from the arc, and scarcely any from the negative carbon.

As the carbon vapor is projected across to the negative carbon, part of it condenses and builds up this carbon to a conical point, though the carbon as a whole burns away.

The positive carbon is supposed to be at a temperature between 5000° C. and 6000° C., while the negative carbon is probably between 2000° C. and 3000° C. On account of this difference in temperature, the positive carbon wastes away faster than the nega-

tive one, and, as it has been said, part of the vapor from the positive carbon condenses on the negative one.

The above considerations are only true for arc lights produced by continuous currents, but if the arc is produced by alternating currents, the electrodes are acted upon alike in every particular, for one is positive at one instant and negative at the next; and they will be consumed at equal rates and will assume the same shape in their tips.

In continuous currents, the rate of consumption of the positive carbon is about twice as great as that of the negative one, and the rate of consumption depends on whether the arc is enclosed or not.

Back E. M. F.—In addition to the ohmic resistance of the arc it has the peculiarity of exerting a *back* or *counter E. M. F.* This back E. M. F. opposes the applied E. M. F. of the circuit producing the arc and seems to range between 35 and 40 volts, many experiments seeming to show that 39 volts is about the average value of this E. M. F. This shows that to operate successfully an arc light. the impressed voltage must be of a value sufficiently high to overcome the back E. M. F. as well as to overcome the ohmic resistance of the arc. This latter varies almost directly with the distance between the carbons. In the arc, it should be remembered that the *voltage* varies directly as the *length of arc* and the *current inversely.* This means that the farther the carbons are apart, the greater the difference of potential between them, and the less the current that flows between them, and to this extent Ohm's law is not applicable.

The explanation of the back E. M. F. is given by Professor S. P. Thompson as follows: In the transformation of the carbon from the solid to the gaseous state, a certain amount of latent heat is absorbed by the vapor without raising its temperature. As this vapor condenses on the negative carbon, this latent heat is released and in doing this it develops, in a reverse sense, the electrical energy which produced the original transformation of the vapor.

Resistance of the Arc.—The true resistance of the arc depends on the *ohmic resistance* of the space separating the carbons, and the resistance of the back E. M. F. which is sometimes called the *apparent resistance.* The ohmic resistance depends on the distance

separating the carbons and may vary between $\frac{1}{10}$ and 10 ohms, while the apparent resistance is a fixed quantity. In an open-type arc taking 10 amperes with a length of arc giving $\frac{1}{2}$ ohm resistance, the E. M. F. necessary to overcome this resistance would be 5 volts, which, added to the 39 volts of the apparent resistance, would make 44 volts necessary to operate such an arc. Ordinary open arc lights take from 45 to 55 volts and enclosed arcs from 60 to 160 volts.

An arc lamp has one length of arc with which it will act best, and a lengthening of it will produce *flaring* of the flame, and the flame will leave the tips and burn around the edges, while a shortening will produce violent hissing and sputtering. With the proper length of arc the flame will burn quietly and smoothly.

Carbons.—The carbons used for arc lights are generally made from graphite, a powdered form of carbon, deposited on the inside of the retorts used in the manufacture of coal gas. It is powdered, mixed with a syrup to make the particles adhere firmly and then molded in the proper form and baked hard. They are made with an inner core of softer carbon, having less resistance than the outside, thereby tending to hold the current near the center of the carbon, facilitating the first formation of the crater in the center and keeping it there. The finished carbons are given a thin electroplated coating of copper which increases the original conductivity of the carbon, besides adding to its duration from 30 to 40 per cent.

The size of the carbons depends on the current used, one for 50 amperes, as a search-light, requiring a diameter about $\frac{22}{32}$ to $\frac{24}{32}$ of an inch. On account of the boiling of the positive carbon, it wears away about twice as fast as the negative one, this last losing by the incandescent particles of carbon being thrown against it, tearing and wearing it away. The negative carbon is smaller in diameter than the positive as it does not lose as much as the positive. The lengths depend on the time they are required to burn, one 12 inches long will burn from 7 to 12 hours in an open arc, but in a closed arc, a pair of ordinary carbons will sometimes last 150 hours.

Regulation of the Arc.—While the arc lasts, the carbons are quickly consumed, and the air gap widens until a point is reached when the resistance is so great that the current will no longer main-

tain the arc and the flame or arc is extinguished. To relight, the carbons must be touched again and at the instant the current flows, must be separated the proper distance.

The lamp of an arc light must then automatically (1) *cause the regular and gradual approach of the carbons towards one another, or one toward the other;* (2) *produce the initial spark by bringing the carbons in contact and separating them the proper distance at the instant current is established;* (3) *hold the carbons at a certain distance, called the length of arc, previously determined for the current used and the intensity of light required.*

The lamp of a search-light must satisfy the above three conditions and in addition must (4) *provide means by which the arc is kept continually in the focus of the mirror,* as the positive carbon wears away faster than the negative one. All four of the above conditions are satisfied in the construction of the search-light lamp, partly by mechanical and partly by electromechanical means.

Principles of Regulation of Search-Light Arcs.

Arc lights used as search-lights on board ship require on an average of 45 volts between the carbons to produce and maintain a steady arc, about 39 volts being absorbed in doing the work of vaporizing the carbon. As search-lights are worked in parallel with incandescent lamps, requiring a higher voltage, a dead resistance must be inserted in each search-light circuit to cut the voltage down to the required difference of potential between the carbons. As the light given out depends on the number of watts absorbed, both the voltage and amperage may be varied, the former, however, within very narrow limits.

We have thus two electrical factors to vary, volts and amperes, the varying factors being the length of arc and the resistance in the circuit. These four are intimately connected, a variation in either the length of arc or of the resistance producing changes either in the difference of potential or current or in both.

For a certain maximum length of arc, the least difference of potential between the carbons is fixed, and with this length of arc the current may be varied by changing the dead resistance. If from any cause the length of arc becomes smaller the difference of

potential decreases, but the current increases without any change in the dead resistance. So, if a certain difference of potential is decided on the current may be carried by a change in the dead resistance.

If a certain current is decided on, it can be obtained by changing the length of arc, or if that is fixed, by changing the resistance, or both may be changed.

If both the differences of potential and current are fixed, the former can be regulated by giving the maximum length of arc, and then the current can be obtained by varying the dead resistance. This last condition is the one generally adopted in actual practice, the difference of potential or maximum length of arc, being adjusted by the tension of a spring acting against the mechanism which feeds the carbons together, and this then being a fixed quantity, the desired current is obtained by one certain fixed resistance. This presupposes that the lamp is perfectly automatic, that is, it keeps the arc constantly at the same length, and if such were the case, it would require no further attention.

However, no lamp is perfectly automatic, and any consequent change in the arc must be corrected, while the lamp is working, by varying the resistance.

In most lamps, there is no provision made for feeding the carbons apart if by any chance they get too close, and while they are naturally wasting away, the current must be controlled by the resistance. If the carbons get too far apart, the mechanism then acts to feed them together.

Action of the Dead Resistance.

Fig. 278 shows the action of the dead resistance in the circuit in causing the necessary drop in potential, R being the resistance introduced in series with the main current and R' representing the resistance of the arc.

If the carbons are far apart, so that R' is practically infinite, a voltmeter connected as shown at V would indicate the full voltage of the circuit and one connected to the terminals of the resistance R would not indicate, the circuit through it not being complete.

If the arc is once struck so that the resistance of the main circuit

is very much lowered, and a large current flows through R', V will then indicate the difference of potential at the carbons, or the fall of potential through R', and V' will indicate the fall of potential through R. Knowing the current desired and the drop through R' necessary, R may be calculated to give the proper drop through it. When the current is flowing the sum of the two readings of V and V' will be the same as that indicated on V when no current was flowing through R'.

The figure shows a typical search-light circuit, ammeter A being inserted in the circuit, V' connected as shown, V being omitted, as the reading obtained by that can be obtained on the switchboard voltmeter, as it is in fact the full voltage of the generators.

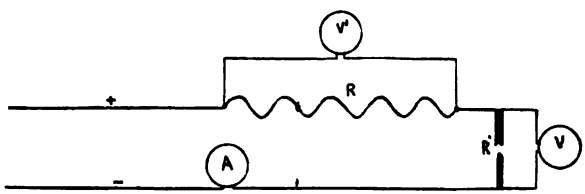


FIG. 278.—Action of Dead Resistance.

The resistance R should always be of such a value as to cause steady working and of sufficient reserve to prevent a short circuit in the mains. It should be sufficiently large to withstand heavy currents without undue heating, with provision for ventilation.

Calculation of R.—Suppose a search-light was to be worked at 50 volts, and of sufficient size to carry 50 amperes, then the resistance of the arc would be, $R = \frac{E}{C}$ or $R = \frac{50}{50} = 1$ ohm. If the full voltage was 80, the fall through the resistance R' must be 80 — 50 = 30 volts. The current through R' being 50 amperes, by Ohm's law $E = CR$ or $R = \frac{E}{C}$, $R = \frac{30}{50} = \frac{3}{5}$ ohms.

The total resistance then in circuit is $1 + \frac{3}{5}$ ohms or $C = \frac{E}{R}$ where E and R represents total E. M. F. and total R,

or $$C = \frac{80}{1 + \frac{3}{5}} = 50 \text{ amperes.}$$

This is also arrived at as follows:

CD is the fall through the arc and DE is the resistance of arc, AB is total fall and x is the resistance to be inserted, then by similar triangles (Fig. 279),

$$\frac{AB}{CD} = \frac{1+x}{1} \text{ or } \frac{80}{50} = 1 + x \text{ or } x = \frac{3}{5}.$$

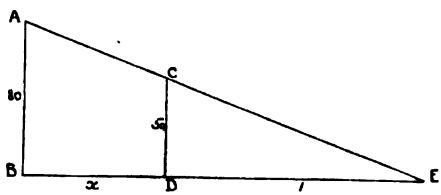


FIG. 279.

Horizontal Lamp.

Having now shown what a good automatic lamp should be capable of doing as explained under regulation of the arc, a description of one horizontal lamp now used in the service will be given.

Fig. 280 is intended to show the general working mechanism of the lamp and the action of the current is making it automatic. Current is brought to the lamp from slide contacts in the projector, these contacts receiving current from the mains through a switch in the pedestal of the projector. When the lamp is placed in position in the barrel of the projector, the terminals of the lamp press against the slide contacts, making sliding connection, to enable the lamp to be moved in and out from the mirror for the purpose of focusing. The lamp terminals are shown at *a*, being one on each side, the further one, positive, not showing in the figure. From the positive terminal, the current flows around an electromagnet *b* in series with the main current; the end of the magnetizing coil being secured at *c*, on the iron piece *d*, which in turn is secured to the core of the electromagnet. The iron piece *d* is in contact with the metal framework of the lamp, the sides of the frame being shown removed. Any part or point of the frame may be considered as the positive terminal of the arc, as it is in direct metallic connection with the main current.

From the piece *d* in contact with the frame, current finds its way through the end pieces of the framework, through the screw spindle *e*, through the two upright supports of the positive carbon *f*, through the positive to the negative carbon, down the two uprights *g*, through the connecting piece *h* to *j* and down the latter to the negative terminal of the lamp. The uprights *g* are insulated from the rest of the framework, this allowing all the framework to be of

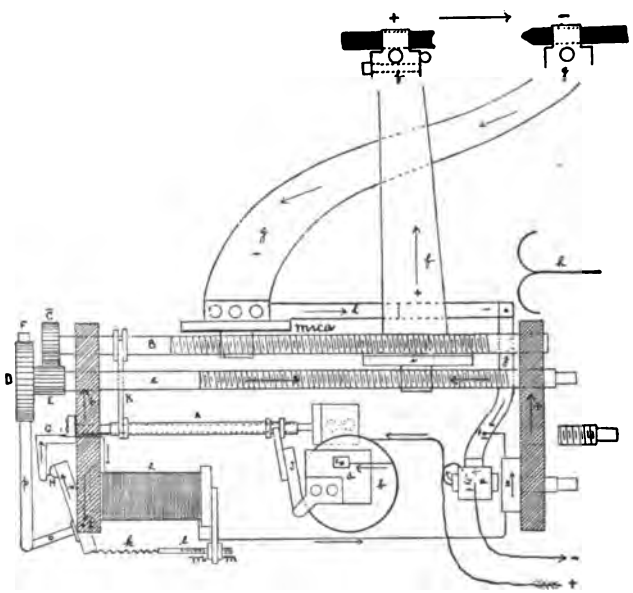


FIG. 280.—Horizontal Lamp.

the same potential. Current also finds its way from the side at *i* to the positive uprights, the uprights *f* being provided with flanges sliding in slots in the side of the frame.

For the automatic working of the lamp, there is a shunt circuit taken from the main current, this shunt circuit controlling the automatic mechanism. The positive terminal of this shunt circuit may be considered as any part of the framework, such as the point where the armature *n* of the electromagnet 2 is pivoted to the frame. The shunt current from here flows through the armature

n, through the flat copper spring *H*, which acts as a contact breaker, through the contact point on the bracket *G*, through the bracket *G* which is insulated from the frame, through and around the electromagnet 2, to the automatic switch 3 and to a point on *j*, acting as the negative terminal.

The two uprights *f* are connected at the bottom by a cross-piece to which is secured a lug with a thread cut in it and through which screws the spindle *e*. A rotary motion given to *e* causes the uprights carrying the positive carbon to move along the spindle. Motion is given to the uprights *g* carrying the negative carbon in a similar manner by the rotation of the spindle *B*. This spindle also has a lengthwise motion through its bearings in the ends of the frame, allowing the uprights to be moved a short distance without a rotary motion of *B*. This provision is made in order to strike the arc, and to do this one carbon must move independently of the other, thus necessitating a flexible connection. In striking the arc, the two uprights *g* move and they are connected to the upright *j*, a rigid solid conductor, by a conductor of flexible copper ribbon, of a shape shown on the right at *h*, so when *g* is moved to the right or left, the copper ribbon bends back or unrolls on itself.

The spindles *B* and *e* are connected to each other through the gear wheels *C* and *E*, and if the spindle *e* is turned the carbons are either brought closer together or further apart, the threads being right-handed and of equal pitch. To make provision for the positive carbon wasting away faster than the negative one and in order to keep the arc always in the same place, the gear wheel *C* is twice the size of *E*, so a motion given to *E* will only cause half the motion in *C*, or in other words, any rotary motion given to the spindle *e* will cause the positive carbon to either approach or recede from the negative one at a rate twice as great as the negative carbon moves.

The uprights holding the carbons have clamp screws to hold them, and the positive one is fitted with tangent screws, by which the end of the positive carbon may be slightly raised or lowered, or turned to the right or the left so as to accurately center the arc, and make the carbons burn evenly.

The movement of the spindle *B* in striking the arc is controlled by the electromagnet *b*, through the armature *J*, sleeve spindle *A*

and rod *K*. *J* is the armature of the series magnet, pivoted as shown, and when attracted towards *d*, communicates its motion through a connecting piece with an end clutch to *A* which slides on a rod, carrying *K* which has a forked arm, engaging the clutch on *B*. When *J* moves to the right the negative carbon moves the same way, the positive one remaining stationary. The amount of motion of *A* to the left is determined by a screw stop-pin through the left-hand end piece and to the right by *J* bringing up against the armature *d*, so the initial separation of the carbons is limited.

n is the armature of the shunt magnet 2, and when this magnet is energized, the armature is attracted, pulling the copper spring contact away from the contact pin, breaking the circuit. The piece *o* pivoted to *p* is rigidly connected to *n*, and when *n* is attracted to the magnet, *p* is pushed up, turning an arm, not shown, carrying a pawl *F* which engages the teeth on *D* connected to the spindle *e*. When the circuit is broken, *n* is pulled back in place by the spiral spring *k*, hooked to a small screw spindle *l*, and in doing so, *p* is pulled down, the pawl *F* revolving the wheel *D*, which sets in motion the spindles *e* and *B*, feeding the carbons together. As soon as the contact spring *H* comes in contact with the point, the circuit is re-established and the same motions repeated. This make and break gives an alternating movement to the feeding pawl as long as current flows through the shunt magnet. There is a stop on the left not shown which regulates how many teeth the pawl *F* engages, so the feeding may be fast or slow.

The tension of the spring *k* regulates the difference of potential at which the carbons will feed, for the greater the tension, the stronger must be the current; or, in other words, the higher the voltage necessary to attract the armature *n*. The tension of the spring *k* is regulated by two stop nuts *m*, *m*.

Suppose the tension on the spring *k* has been regulated to give the difference of potential at which it is required the carbons will feed and the carbons are just touching. The main switch at the base of the projector is turned, and immediately the whole current flows through the series magnet, the circuit being completed through the carbons. At this instant, the series magnet *b* is energized and the armature *J* attracted, and as has been explained the negative

carbon is drawn away from the positive, striking the arc. The resistance of the arc at this time is such that all the current flows through the carbons, there not being enough difference of potential between the carbons to cause enough current to flow through the shunt magnet to overcome the tension of the spring *k*. The carbons gradually burn away, and as they do, the resistance of the arc increases, the difference of potential increases to the amount for which the spring *k* was set and current flows through the shunt magnet. This starts the feeding mechanism as explained and the carbons are fed together again, the difference of potential gradually falling until the spring overcomes the shunt current and the feeding stops. This arrangement constitutes the automatic working of the lamp. If by any chance the carbons get too close, there is no provision made for feeding them apart and they must burn away.

If it is required to work the lamp by hand, the automatic switch 3 is turned by a wrench on the right-hand end, and this simply breaks the shunt circuit, when the carbons can be fed by a wrench on the end of the spindle *e*.

In order that the arc may be accurately put in the focus of the mirror, there is a screw spindle, projecting through the projector which screws into a screw thread cut in the face of the lamp frame, and turning this moves the lamp towards or from the mirror.

In horizontal lamps, there is a tendency for the flame to ascend, due to the heated air, and to prevent this, and to center the arc and make it burn evenly there is a ring of magnetic material surrounding the arc. This creates a uniform magnetic field around the arc which centers it and makes it burn evenly.

The Balancer.

The introduction of a dead resistance in the leads of a search-light arc to reduce the generator voltage to that required to sustain the arc results in the expenditure of energy that does not appear as light. This loss is not so great when the arcs take small current and the search-lights are few in number, but as both the size and number increase the waste energy becomes a matter of great importance.

In the example given, the energy consumed is $80 \times 50 = 4000$

watts, of which the arc only consumes $50 \times 50 = 2500$ watts, a waste of 37.5 per cent, and numerically 2 horsepower. This loss takes place in the dead resistance and is dissipated in the form of heat, the C^2R loss being $50 \times 50 \times \frac{3}{5} = 1500$ watts.

To reduce this loss, the machine known as the **balancer** has been devised. This is similar in appearance to a motor generator, with the field of the motor in series with the armature while the generator field is differential wound. Its action will be understood by reference to Fig. 281, which shows the method of connection to the leads.

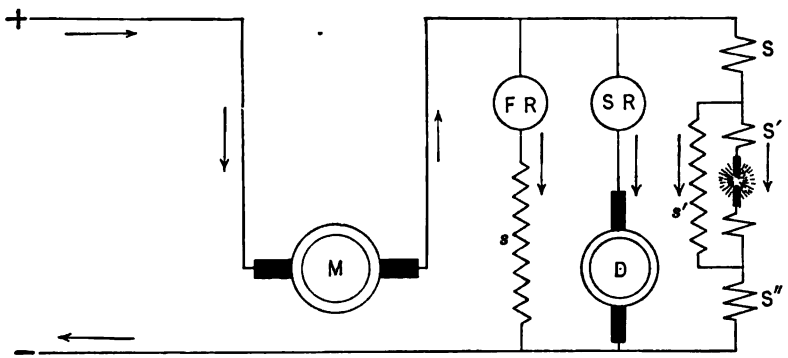


FIG. 281.—**Elementary Connections of the Balancer.**

The arc leads are marked + and — (Fig. 281), with the motor M connected in the line, and S is its series field. D is the generator connected directly across the line with its shunt field s, FR, field rheostat, and SR a starting rheostat. S'' is the series field of D wound differentially with respect to s. S' is the series winding and s' the shunt winding of the lamp-regulating mechanism.

When the carbons are separated and the main switch closed, current flows as indicated by the arrows. Under this condition, D acts as a motor under the action of the constant field due to s and drives M. The current through M is small, as the carbons are separated, and the resistance of s' is high. From the fact that the current is small, the field of M through S is but feebly energized, consequently the counter E. M. F. of M is low, and the fall of potential through M is also low, being equal to $c_a r_a$ of M. The

terminals of the lamp shunt *s'* receive practically the full voltage of the line and the shunt current acts to feed the carbons together.

As soon as the carbons touch and current flows through them, the entire condition is changed. The field of *M, S,* is now fully energized and *M* now acts as the prime mover, driving the armature of *D*. This current flowing through *S''* reduces the field of *D,* as the fields are oppositely wound, and reduces the counter E. M. F. *D* acts as a generator and the current through it is reversed. The counter E. M. F. of *M* increases as the field is strengthened, and the excess of line voltage over that required for the maintenance of the arc is represented by the counter E. M. F. developed. The current through *M* depends on the difference of potential at the carbons, on the counter E. M. F. and on the armature resistance, and it may be lower than that required to actuate the arc, in which case the deficiency is made up by that generated by *D*. This represents the saving effected by this device as the current is not drawn from the main generator.

As the carbons burn apart and the resistance increases, the field current of *M* decreases and the armature speeds up. This decrease of current decreases the series effect of *D,* and both causes, the increase of speed and field, results in an increase of the difference of potential at the lamp shunt terminals and the carbons are fed together.

If the carbons get too close together the increased current causes *M* to slow down, and also decreases the field of *D* which causes it to lower the voltage at the carbon terminals.

Search-Light Projectors.

The projector carrying the lamp consists of a fixed pedestal surmounted by a turntable carrying the projector proper. The pedestal is arranged so it can be securely bolted to the deck or platform and fitted to contain the electrical connections.

The turntable is so designed that it can be revolved in a horizontal flame freely and indefinitely in either direction or clamped rigid if desired.

The drum is trunnioned on two arms bolted to the turntable and has free movement in a vertical plane of 70° above and 30° below

the horizontal. The drum can be rotated on its trunnions by hand or clamped rigidly in any position, and while clamped may be given a slow movement in altitude by turning a small handle in the axis of the pedestal. The drum is fitted with peep sights for observing the arc in two planes, in the side by a colored piece of glass and in the top by reflecting prisms. The drum is designed to contain a parabolic mirror.

The mirror is of the best quality of glass and should be free from all flaws and holes, with its surface ground to exact dimensions. The back is silvered in such a way as to be unaffected by heat. The glass is mounted in a separate metal frame lined with a non-conducting material to allow for expansion due to heat, and to prevent injury from concussion.

The front of the drum is provided with a glass door composed of strips of clear plate glass.

The lamps produce the best results when taking current as follows:

13-inch	18	to 20	amperes.
18-inch	30	" 35	"
24-inch	40	" 50	"
30-inch	70	" 80	"
60-inch	150	" 200	"

The 18-inch projector is supposed to project a beam of light of such intensity as to render plainly discernible, on a clear dark night, a light-colored object 10 × 20 feet in size, at a distance of not less than 4000 yards, the 24-inch projector at a distance of not less than 5000 yards and the 30-inch projector at a distance of not less than 6000 yards.

For the care and management of search-lights see chapter XXXV.

Enclosed Arc Lamps.

Enclosed arc lamps are now being used on shipboard to some extent, especially in engine-rooms, where a large area requires general illumination. These lamps differ from ordinary arc lights in that the arc is surrounded by a small glass globe which fits the carbons so closely that the air inside the globe can only slowly change. One effect of this is to reduce the rate of combustion of

the carbons which also lessens the work of the feeding mechanism. The enclosed air becomes a source of light, so that the whole globe seems to glow and increases the apparent amount of light.

Enclosed arc lights require a higher voltage than open arcs, 60 volts being about the minimum, and take from 2 to 10 amperes.

Lamps are furnished to operate on voltage of 80, 110 or 125 volts with a current not exceeding 4.5 amperes. The arc is enclosed by an inner opal globe, which is surrounded by a clear globe protected by a composition guard. The guard and outer globe are removed together and so held by supporting chains that the inner globe may be removed to renew the carbons.

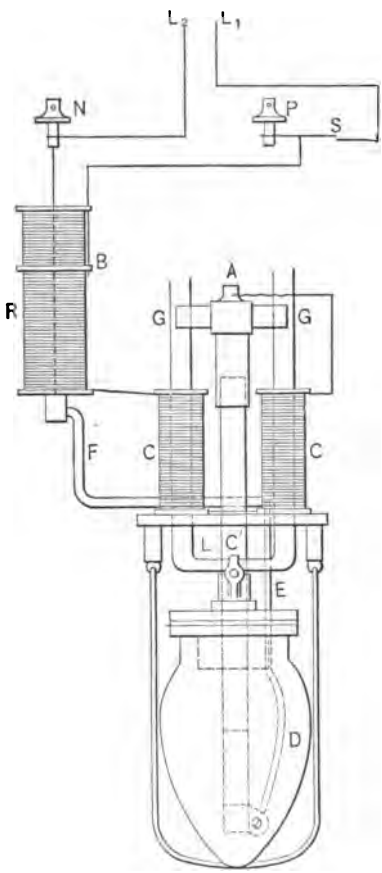


FIG. 282.—Form 12 Arc Lamp. General Electric Company.

Carbons are $\frac{1}{2}$ inch in diameter and have a life of 120 hours without trimming.

Each lamp contains the proper resistance for reducing the line voltage to that required for the best regulation of the arc, an average of about 85 volts.

A commercial form of lamp that meets the required specifications is made by the General Electric Company and is shown diagrammatically in Fig. 282. L_1 and L_2 are the line leads, and are wired in multiple from the lighting mains. L_1 is connected to the positive terminal of the lamp P, through the switch S, on top of the lamp. From the positive terminal, the circuit leads to the edgewise wound rheostat R, through the sliding contact B, which can

be moved up or down along the rheostat. This throws more or less of the resistance of R into circuit and acts as the dead resistance previously described. From the rheostat the circuit leads to the electromagnets *C, C,* and thence to the terminal *A,* which is a part of the support holding the upper, positive, carbon of the lamp. Current flows from the positive carbon to the lower, negative, carbon, then to the curved conductor *D,* vertical conductor *E* and curved conductor *F,* up through the center of the rheostat to the negative terminal *N* of the lamp and thence to the line lead L_2.

The positive carbon is held by a clutch *C'* through a bell crank arm and acts to grip the carbon and raise it when the support is raised, but on lowering when the clutch comes against the top of the inner globe support, the clutch opens and allows the carbon to fall until it brings up against the negative carbon, so at all times the lamp is ready for operation.

Before current is switched on the carbons touch, but as soon as the electromagnets are energized, the plunger *L* is sucked into the core of the solenoid, and at the same time the clutch grips the positive carbon, raising it, and thus strikes the arc. As the carbons burn away and the length of arc increases, the resistance increases, consequently the current through the arc lessens and the plunger is not held so strongly in the magnets and it drops, until the increased current is sufficient to hold it at the proper distance for the voltage across the arc.

The working mechanism of the lamp is protected from dust and dirt by a bronze sheet-copper casing, and there should be no occasion to remove this as the rheostat is properly adjusted and should not be changed.

Candle-Power of Arc Lights.

The candle-power of arc lights is rather a deceptive means of determining how much light an arc is producing. For instance, a so-called 2000-candle-power arc light does not give more than 1400 candle-power in the direction of greatest intensity. The same considerations hold for arc lights as for incandescent lights regarding their mean spherical candle-power; that is, it is the average candle-power on the surface of a sphere with the light at the center.

However, there is a great difference between the horizontal candle-power and the maximum candle-power, the latter being found, in vertical arcs with the + carbon uppermost on a line making an angle of 45° with the horizontal. This is due, of course, to the reflection from the crater on the positive carbon, this acting as a reflector and throwing the light down, and besides the incandescence of the positive carbon being the principal source of light.

An empirical rule for finding the mean spherical candle-power is to add one-half the mean horizontal candle-power and one-quarter of the maximum candle-power. From the direction of the maximum ray, it is very evident that for a search-light to give out the most light, the carbons should be so placed that the rays of greatest intensity shall be the ones that should be reflected from the mirror. In other words, the carbons should be horizontal, with the positive carbon farthest from and pointed towards the mirror, and this is the case with all present designs of search-lights.

The practical method of determining the candle-power is to find the power in watts absorbed to produce it. The mean spherical candle-power can be determined by using the arc in connection with the photometer, finding both the horizontal and maximum candle-power; and at the same time by properly connecting a voltmeter and ammeter, the number of watts absorbed can be found. When the arc is used as a search-light, and the product of the volts and amperes show a value equal to that found when the candle-power was being tested then the arc is producing its rated candle-power. Different shaped carbons or different adjustments may vary the intensity or direction of the maximum ray, but with the same number of watts, the *mean* candle-power remains practically the same.

The maximum candle-power can be determined by connecting a voltmeter and ammeter in circuit, and varying these quantities until their product is a maximum. The range of voltage is practically limited to a few volts, the greatest current consistent with steadiness of arc, proper length of arc and the carrying capacity of the carbons may be found. When a light is being used under the conditions determined for maximum candle-power, or the product of the two variables is the same, then it may be certain that the arc is giving its maximum mean spherical candle-power.

Flaming Arc Lights.

In the ordinary carbon arc light, most of the light is produced by the incandescence of the carbon terminals, and improvements have been made in making the arc itself luminous. The addition of materials such as calcium and strontium to the carbons results in the production of very highly luminous and efficient arcs. The carbons produce a vapor path by which the light-producing materials are conveyed from one terminal to the other. From the appearance of these arcs, they are called "flaming arc" lamps. Their efficiency is about ten times as great as that of the carbon arc. On account of the fumes given off by these arcs they can only be used for outdoor lighting or in places where there is good ventilation.

Mercury Vapor Lamps.

This lamp consists of a glass tube, which may be of different lengths, exhausted of air and connected to a reservoir of mercury. This metallic mercury forms one electrode while the other is at the end of the tube farthest from the reservoir. The arc is started by tilting the tube, making metallic contact from one electrode to the other. The heat produced by the current maintains a supply of vapor which forms a conducting path for the current. This condenses along the sides of the tube and runs down again to the reservoir. This lamp gives off a greenish light of very high intensity. The spectrum shows an absence of all red rays, and the light cannot be used when colors are to be compared, but makes a very satisfactory light for general illumination or reading. To a certain extent the candle-power of the lamp is controlled by the diameter of the tube.

CHAPTER XXVI.

WIRES.

The size of a conductor necessary to carry a given current is determined by its area of cross-section, and this may be any of the ordinary shapes; square, rectangular or circular, the latter being the most common. If the cross-sectional area be circular, as a wire, the conducting area may be one large wire, or a collection of wires stranded together carrying the current in parallel and whose area is collectively equal to the large wire.

Circular Mil.—Electricians use as a unit of sectional measure an area whose value is one **circular mil.** The mil is a linear measure and is equal to .001 of an inch. If a round wire has a diameter of one mil, then the area of cross-section of that wire is one circular mil.

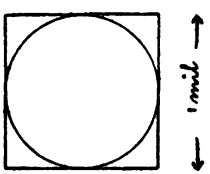


FIG. 283.

The **square mil** is sometimes used as a unit of area, being the area of a square .001 inch on a side. The number of circular mils multiplied by .7854 gives the number of square mils; and the number of square mils multiplied by 1.273 gives the number of circular mils. This is shown in the relation between the area of a circle and the circumscribed square, 1 mil on the side (Fig. 283),

$$\text{area of circle} = \frac{\pi d^2}{4} = \frac{3.1416}{4} \times 1^2 = .7854 \text{ sq. mils} = 1 \text{ cir. mil},$$

$$\text{area of square} = 1 \times 1 = 1 \text{ sq. mil},$$

$$\text{or} \quad .7854 \times 1 \text{ sq. mil} = 1 \text{ cir. mil},$$

$$1 \text{ cir. mil.} \times 1.273 = 1 \text{ sq. mil}.$$

When the diameter of the wire is .001 inch or one mil, the circular area is $.001^2 \times .7854 = .0000007854$ square inch, or one circular mil = .0000007854 square inch.

Suppose it was required to express in circular mils the area of

cross-section of a wire 1 inch in diameter. The area of this circle would be

$$\frac{\pi d^2}{4} = .7854 \times 1^2 = .7854 \text{ sq. inches.}$$

But $$1 \text{ cir. mil} = .0000007854 \text{ sq. inches,}$$

$$\therefore \quad \text{No. of cir. mils} = \frac{.7854}{.0000007854} = 1{,}000{,}000.$$

This number is the square of the diameter expressed in mils, as one inch equals one thousand mils; hence we have the rule: To express the cross-sectional area of wires in circular mils, we multiply the diameter of the wire expressed in mils by itself; or, in other words, *the square of the diameter expressed in mils is equal to the area in circular mils.*

To express the cross-sectional area of a rectangular or square-shaped conductor in circular mils, it is necessary first to find the area in square inches, and reduce that to circular mils.

$$1 \text{ sq. inch} = 1{,}000 \times 1{,}000 = 1{,}000{,}000 \text{ sq. mils,}$$
$$1 \text{ sq. mil} = 1.273 \text{ cir. mils,}$$
or $$1 \text{ sq. inch} = 1{,}273{,}000 \text{ cir. mils.}$$

So to find the area of a bus bar, for instance, first find its area in square inches and multiply by 1,273,000, and the result will be circular mils.

Wire Tables.

Wires are made in standard sizes, and numbers are given each size, this number expressing the area of cross-section in circular mils as determined by their diameters. Gauges are made by which the diameters of wires are measured, and a reference to a wire table made for the gauges used gives the area in circular mils. The two principal wire tables and gauges are those of Brown & Sharpe in America and the Birmingham in England, called respectively the B. & S. gauge and B. W. G. gauge.

In the following table the dimensions are given for single wires, though conductors are rarely composed of only one wire, but rather made up of stranded wires, such that the carrying capacity of the stranded wires in parallel is approximately equal to one large con-

ductor. For instance, suppose a wire of 30,000 circular mils was required; a No. 7 B. W. G. would answer the purpose, but for pliability and ease in installing, it would usually be made up of 7 strands of No. 16 B. W. G., giving $7 \times 4225 = 29{,}575$ circular mils or 19 strands of No. 18 B. & S., giving $19 \times 1624 = 30{,}856$ circular mils.

WIRE TABLES.

Gauge.		Diam.	Area.		Gauge.		Diam.	Area.	
B. & S.	B.W.G.	Inches.	Sq. in.	Cir. Mils.	B. & S.	B.W.G.	Inches.	Sq. in.	Cir. Mils.
0000	.....	.460	.1662	211.600	....	8	.165	.0214	27.225
....	0000	.454	.1618	206.116	6	....	.162	.0206	26.250
....	000	.435	.1410	180.525	....	9	148	.0172	21.904
000	....	.409	.1318	167.800	7	. .	.144	.0163	20.736
....	00	.380	.1134	144.400	....	10	.134	.0141	17.956
00	....	.364	.1046	133.100	8	....	.128	.0129	16.510
....	0	.340	.0908	115.600	....	12	.109	.0093	11.881
0	....	.324	.0824	105.500	10	....	.102	.0082	10.380
....	1	.300	.0727	90.000	....	14	.083	.0054	6.889
1	....	.289	.0657	83.690	11	....	.09074	.0065	8.234
....	2	.284	.0633	80.556	12	....	.081	.0051	6.530
...	3	.259	.0527	67.081	....	16	.065	.0033	4.225
2	....	.257	.0521	66.370	13	....	.07196	.00407	5.178
....	4	.238	.0445	56.644	14	....	.0641	.0032	4.107
3	....	.229	.0413	52.630	....	18	.049	.0019	2.401
....	5	.220	.0380	48.400	15	...	.05707	.00256	3.257
4	....	.204	.0328	41.740	16	....	.051	.0020	2.588
....	6	.203	.0324	41.209	17	....	.04526	.00161	2.048
5	....	.182	.0260	33.100	18	....	.040	.0013	1.624
....	7	.180	.0254	32.400	19	....	.03589	.00110	1.288

Wires are usually referred to as so many even thousand circular mils; thus a No. 16 B. W. G. is 4225 circular mils and a No. 14 B. & S. is 4107 circular mils, both of which would be spoken of as 4000 circular mil wire.

For ship installation when a conducting area greater than that of No. 14 B. & S. is required, the conductor is stranded, the complete wire being composed of an odd number of strands, and the size of strands and single conductors are determined by the B. & S. gauge. The conductors are stranded in a series of 7, 19, 37, 61, 91 or 127 wires as required. The total conductor consists of a central strand, the remainder laid around it concentrically, each layer twisted in the opposite direction from the preceding.

The following table gives the actual size of wires and the number of strands as manufactured for the navy:

Approx. C. M.	Actual C. M.	No. wires in strand.	Size of wire, B. & S. G.	Diameter inches.		Diameter in 32ds of an inch.		
				Over copper.	Over Para rubber.	Over vulc. rubber.	Over tape.	Over all insulation.
			No.					
4,000	4,107	1	14	.06408	.0953	7	9	11
9,000	9,016	7	19	.10767	.1389	10	12	14
11,000	11,368	7	18	.12090	.1522	10	12	14
15,000	14,336	7	17	.13578	.1670	10	12	14
18,000	18,081	7	16	.15225	.1837	11	13	15
20,000	22,799	7	15	.17121	.2025	12	14	16
30,000	30,856	19	18	.20150	.2328	12	14	16
40,000	38,912	19	17	.22680	.2576	13	15	17
50,000	49,077	19	16	.25410	.2854	14	16	18
60,000	60,068	37	18	.28210	.3134	15	17	19
75,000	75,776	37	17	.31682	.3481	16	18	20
100,000	99,064	61	18	.36270	.3940	18	20	22
125,000	124,928	61	17	.40734	.4386	19	21	23
150,000	157,563	61	16	.45788	.4885	20	22	24
200,000	198,677	61	15	.51363	.5449	22	24	26
250,000	250,527	61	14	.57672	.6080	24	26	28
300,000	296,387	91	15	.62777	.6590	26	28	30
375,000	373,737	91	14	.70488	.7381	29	31	33
400,000	413,639	127	15	.74191	.7782	30	32	34
500,000	521,589	127	14	.83304	.8643	32	34	38
650,000	657,606	127	13	.93548	.9667	35	37	42
800,000	829,310	127	12	1.05058	1.0818	39	41	46
1,000,000	1,045,718	127	11	1.17962	1.2109	43	45	50
			WIRES USED IN STRANDS.					
.....	1,288	.....	19	.06589	.....	.....	....	....
.....	1,624	.....	18	.04080	.....	.....	....	....
.....	2,048	.....	17	.04526	.....	.....	....	....
.....	2,583	.....	16	.05082	.....	.....	....	....
.....	3,257	.....	15	.05707	.....	.....	....	..
.....	4,107	.....	14	.06408	.....	.....	....	....
.....	5,178	.....	13	.07196	.....	.....	....	....
.....	6,530	.....	12	.08081	.....	.....	....	....
.....	8,234	.....	11	.09074	.....	.....	....	....

Insulation of Lighting Wire.

Lighting wire used for light and power mains is classed as *single conductor, twin conductor* and *double conductor.* The standard dimensions for single conductor is given in the preceding table. All conductors are of soft annealed pure copper wire. The conductivity of each single wire must be not less than 98 per cent of pure copper of the same number of circular mils, and the conductivity of the whole standard conductor must be at least 95 per cent of pure copper of the same number of circular mils.

Each wire, whether forming a single conductor or a strand of a stranded conductor, is thoroughly and even tinned. This is to

prevent any corrosive action between the sulphur in the vulcanized rubber and the copper of the wires.

All **single conductors** are insulated as follows:

1. A layer of pure Para rubber $\frac{1}{64}$ inch thick, **rolled on.**
2. A layer of vulcanized rubber.
3. A layer of cotton tape.
4. A close braid of No. 20 2-ply cotton thread braided with three ends for all conductors under 60,000 circular mils, and No. 16 3-ply cotton thread, braided with four ends, for all conductors of and above 60,000 circular mils.

Twin Conductors.—The standard dimensions for these conductors are given in the following table:

Approx. C. M.	Actual C. M.	No. wires in strand.	Size of wire, B. & S. G.	Diameter in inches.		Diameter in 32ds of an inch.						
				Over copper.	Over Para rubber.	Over vulcanized rubber.	Over tape.		Over 1st braid.		Over 2d braid.	
							One conductor.	Two conductors.	One conductor.	Two conductors.	One conductor.	Two conductors.
			No.									
4,000	4,107	1	14	.06408	.092	5	6	12	8	14	10	15
9,000	9,016	7	19	.10767	.139	7	9	18	11	20	13	21
11,000	11,368	7	18	.12090	.156	8	10	20	12	22	14	23
15,000	14,396	7	17	.13578	.172	8	10	20	12	22	14	23
18,000	18,081	7	16	.15225	.190	9	11	22	13	24	15	25
20,000	22,799	7	15	.17121	.209	10	12	24	14	26	16	27
30,000	30,856	19	18	.20150	.243	11	13	26	15	28	17	29
40,000	38,912	19	17	.22630	.268	12	14	28	16	30	18	31
50,000	49,077	19	16	.25410	.298	13	15	30	17	32	19	33
60,000	60,088	37	18	.28210	.327	14	16	32	18	34	20	35

All twin lighting conductors consist of two conductors, each of which is insulated as follows:

1. A layer of pure Para rubber $\frac{1}{64}$ inch in thickness, rolled on.
2. A layer of vulcanized rubber.
3. A layer of cotton tape, lapped $\frac{1}{32}$ inch.

Two such insulated conductors are laid together, the interstices filled with jute and covered with two layers of close braid. Each braid is made of No. 20 2-ply cotton thread, braided with three ends.

Double Conductors.—These are of three varieties, *double conductor, plain; double conductor, silk,* and *double conductor, diving lamp.*

Double Conductor, Plain.—Each conductor is constructed as follows:

1. A copper conductor consisting of seven No. 22 B. & S. G. tinned annealed pure copper wires, six of the wires lying around the seventh. One conductor is covered with:

1. A layer of vulcanized rubber.

2. A close braid of No. 60 cotton thread, braided with three ends.

This conductor forms the core, and the wires of the second conductor are laid around it over the braid concentrically and smoothly.

Over both conductors are:

1. A close braid of No. 60 cotton thread, braided with three ends.

2. A layer of vulcanized rubber.

3. A layer of cotton tape $\frac{1}{32}$ inch in thickness.

4. A close braid of No. 30 3-ply linen gilling thread, braided with two ends.

5. A close braid of No. 30 3-ply linen gilling thread, braided with three ends.

The fourth and fifth layers of braid are thoroughly saturated with a water-excluding compound of such a character as not to injure the braid or to render the conductor less pliable.

Double Conductor, Silk.—Each conductor is constructed as follows:

1. A stranded copper conductor consisting of seven No. 25 B. & S. G. untinned annealed copper wires, six wires lying concentrically around the seventh.

2. A close braid made of No. 80 Sea Island cotton thread.

3. A layer of pure Para rubber to a diameter of $\frac{4}{32}$ inch.

4. A close braid of No. 60 cotton thread.

5. A close braid of hard twisted olive-green silk.

6. Two conductors thus constructed are twisted together to form the finished conductor.

Double Conductor, Diving Lamp.—Each conductor is constructed as follows:

1. A copper conductor consisting of seven No. 20 B. & S. G. tinned annealed copper wires, six of the wires lying around the seventh.

2. A layer of pure Para rubber rolled on to a thickness of not less than $\frac{1}{64}$ inch.

3. A layer of vulcanized rubber.

Two conductors thus constructed are laid up or twisted together and filled with jute saturated with an insulating compound. The conductors are then covered with:

1. A layer of vulcanized rubber to a diameter of $\frac{5}{32}$ inch.

2. A close braid of No. 30 3-ply linen gilling thread, braided with three ends.

3. A close braid of No. 30 3-ply linen gilling thread, braided with four ends.

Tests.

All wires are subjected to a test for continuity and for insulating properties; the latter by measurement of insulation resistance and by high potential test on the entire length of the cables, either or both, as per the following table:

	Insulation resistance.	Test voltage, 30 minutes.
Lighting wire.		
Up to and including:		
500,000 c. m., single	1000 megohms per knot	4500
650,000 c. m., single	900 megohms per knot	4500
800,000 c. m., single	800 megohms per knot	4500
1,000,000 c. m., single	750 megohms per knot	4500
All twin wire:		
Between conductors	1000 megohms per knot	3500
From conductors to ground	1000 megohms per knot	3500
Double conductor.		
Plain:		
Between conductors	1000 megohms per 1000 feet	2500
Each conductor to ground	1000 megohms per 1000 feet	3500
Diving:		
Between conductors	1000 megohms per 1000 feet	3500
Each conductor to ground	1000 megohms per 1000 feet	3500
Silk	No test	5000

Tests for insulation resistance are made after immersion of wire (not less than three days after manufacture, the three days to be

reckoned back from the end of the immersion period) in fresh water at a temperature of 22° C. for a period of twenty-four hours, the test to be made by the direct-deflection method at a potential of 500 volts after five minutes electrification.

High-potential tests shall then be made with the wire still immersed, the source of power supply to be a transformer of not less than 5-kilowatt capacity. For double-conductor silk and bell cord the high-potential tests will be made with the dry wire freely suspended in the air.

Tests are also made to determine the percentage of water absorbed by the braids, after samples have been immersed in fresh water at 22° C. for a period of twenty-four hours.

The braid and insulation must show no breaking or cracking when samples are bent to a radius of seven times the diameter after having been exposed for several hours at a time, alternately to a temperature of 95° C. and the temperature of the atmosphere over a period of three days.

Specifications for Size.

Search-Light Circuits.—The feeders of search-lights are of sizes given in the following table:

Size of searchlight.	Size of feeder. c. m.
13-inch	18,081
18-inch	30,856
24-inch	38,912
30-inch	60,088

Lighting Circuits.—The maximum load for any feeder for lighting circuits shall not exceed 75 amperes, this on a basis of .5 ampere for 16-candle-power incandescent lamps or $\frac{1}{12}$-horsepower fans and 1 ampere for 32-candle-power lamps of $\frac{1}{6}$-horsepower fans.

Several mains may be fed by the same feeder provided the total load is not in excess of 75 amperes as specified above.

The area of cross-section of the feeders and mains on the lighting circuits shall be such that the fall in potential from the generator terminals to the most distant outlet shall not be more than 3 per cent at the normal load of the feeder.

Any reduction in the size of a feeder or a main shall be fused unless the fuse which protects the larger size wire is small enough to hold the normal current in the smaller wire down to 1 ampere per 1000 circular mils cross-section of wire; *i. e.*, fuse is to blow when current density reaches 500 circular mils per ampere.

No feeder or main shall have a cross-section that will give a current desnsity greater than 1000 circular mils per ampere at the normal load.

Feeders which interconnect shall have an area of cross-section of not less than 1500 circular mils per ampere at the normal load.

Branches for single lights, in conduit wiring, are made of 4107 circular mils twin conductor. Leads from distribution boxes to single outlets are run with 4107 twin conductor.

Motor Circuits.—Motors whose normal full-load working currents are less than 50 amperes may be grouped on the same feeder, but no such feeder must have a load in excess of 100 amperes. Each motor whose normal full-load working current exceeds 50 amperes has a separate feeder.

Feeders and mains have a cross-section not less than 1000 circular mils per ampere for continuous service and not less than 500 circular mils per ampere for intermittent service.

Calculation for Size.

In calculating the size of wires for a certain circuit on board ship, two requirements must be met: first, the wires must be large enough to carry their loads without undue heating, and second, they must be large enough so that the fall of potential or *drop* due to the resistance of the conductors themselves shall not exceed a certain amount.

The first requirement is met by the standard specifications which state that the safe-carrying load shall be at the rate of 1000 amperes per square inch of conductor, and experiment shows that this proportion is entirely safe, the factor of safety being sufficient. The second requirement is that the total drop from the generator to the farthest lamp shall be not more than 3 per cent of the total difference of potential at the generator, this drop being due to the resistance of the conductors.

The calculations can best be illustrated by an example showing how to find the sizes for feeder, mains and branches in a typical feeder circuit to meet the two requirements for heating and drop. To take a simple case, suppose a main runs along the gun-deck of a vessel, lights being taken from it along its length, and that the main is supplied by a feeder from the switchboard at a point such that the total current is equally divided, or nearly so, on each side of the feeding center. This is represented by the figure.

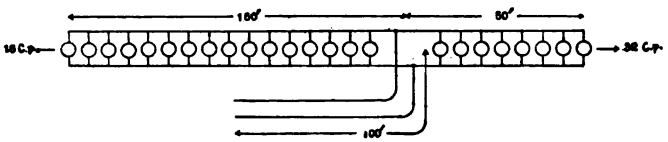


FIG. 284.

Fig. 284 represents a main of total double length of 200 feet fed by a feeder of 100 feet double-carrying length. There are twenty-four lamps represented, sixteen 16-candle-power and eight 32-candle-power. For calculation of wire sizes an efficiency of 4 watts per candle-power can be assumed, which on an 80-volt circuit would mean a current of .8 ampere per lamp, for

$$CE = \text{No. of watts} = 4 \times 16 = 64 \text{ watts per lamp,}$$

$$\text{or } C \text{ per lamp} = \frac{64}{80} = .8 \text{ ampere.}$$

Each 32-candle-power lamp would take 1.6 amperes. The total load then due to the 16-candle-power lamp is $16 \times .8 = 12.8$ amperes, and that due to the 32-candle-power lamp is $16 \times .8 = 12.8$ amperes. The feeder must supply 25.6 amperes, and the feeding center at such a point that the load on each side of the feeder is equal, viz.: 12.8 amperes, which has been assumed 50 feet from one end.

When the wire list is being prepared it is usual to mark the location and character of all lights on the blue prints of the ship, and draw the mains, by which means the exact total load the mains must carry is determined, and also the length of the mains. The proper feeding center is then determined on and the length of the feeder to the switchboard measured.

The resistance of a foot of copper wire at 75° F., and 1 mil in diameter, or 1 mil-foot, is 10.79 ohms, and since resistance varies directly as the length and inversely as the cross-sectional area, the general formula for resistance would be

$$R = \frac{10.79 \times L}{d^2} \qquad \text{(a)}$$

where

L = length in feet,
d = diameter in mils,
or d^2 = area in circular mils.

From Ohm's law $C = \frac{e}{R}$. (b)

Where e is the fall of potential between two points whose resistance is R and through which a current C is flowing. If R is the resistance of the conductor, then e is the drop due to this resistance, which is the value sought.

Substituting the value of R in (b) in (a) we have the value

$$d^2 = \frac{10.79 \times L \times C}{e},$$

and thus knowing the three quantities L, C and e, the proper size wire can be calculated.

It is, however, usual to see if the size for heating is sufficiently large to meet the requirements for drop, and if it is, there is no further calculation necessary, but if not, the size for heating must be increased.

Allowing for heating alone at the rate of 1000 amperes per square inch, 1 ampere would require 1000 circular mils and the size for heating for the feeder would be $25.6 \times 1000 = 25{,}600$ circular mils. The drop for this size would be

$$e = \frac{200 \times 25.6 \times 10.79}{25{,}600} = 2.16 \text{ volts.}$$

This shows that though large enough for heating, that size is too small for the drop, leaving, as it does, only .24 volt for the drop in the mains (3% of 80 — 2.16 = .24). As a rule half the drop should take place in the feeder unless it is much shorter than the

mains, and assuming that $\frac{3\% \times 80}{2} = 1.2$ volts is the drop in the feeder, then

$$d^2 = \frac{200 \times 25.6 \times 10.79}{1.2} = 46{,}037 \text{ circular mils.}$$

The nearest manufactured size to this would be $\frac{19}{16}$ B. & S., or $19 \times 2583 = 49{,}077$ circular mils, and again using this value

$$e = \frac{200 \times 25.6 \times 10.79}{49{,}077} = 1.12 \text{ volts.}$$

Now taking up the drop in the mains, it is seen that there are 12.8 amperes carried 150 feet on one side of the feeding center, and 12.8 amperes carried 50 feet on the other, and it is evident that the longer circuit must be calculated for.

The whole load of 12.8 amperes is not carried the whole length of 150 double, or 300 feet, and the drop is proportional to the resistance. The lamps are taken off at practically equal distances, so the drop can be calculated on any average resistance, or for an average distance, or half the whole distance. In other words, the calculated drop for the whole distance is twice the actual drop.

It will be shown that the drop in any of the branches is practically nothing, so that the drop in the mains, counting the total length is $2.4 = 1.12 + \frac{x}{2}$ or $x = 2.56$,

or

$$d^2 = \frac{300 \times 12.8 \times 10.79}{2.56} = 16{,}184.$$

Using the nearest manufactured size $\frac{7}{16}$ B. & S. or 18,081 circular mils

$$e = \frac{300 \times 12.8 \times 10.79}{18{,}081} = 2.29.$$

The total drop then is $1.12 + \frac{2.29}{2} = 2.26$, which is within the 3 per cent limit, leaving .14 for the drop in the longest branch.

All branch wire is No. 14 B. & S. or 4107 circular mils, so the drop in a branch 50 double feet would be

$$e = \frac{50 \times .8 \times 10.79}{4107} = .10509,$$

or per single foot of mains as installed $\frac{.10509}{25} = .004$.

The size of wire for this circuit would then be: feeder 49,077 circular mils; mains 18,081 circular mils, and branches 4107 circular mils.

The section in the mains 50 feet in length could be made of smaller wire, for the drop there with the above-sized wire would not be as great, but it is usual to make the mains the same size throughout.

The feeder might be made smaller and the mains larger and still be within the limit and the selection would depend upon the quantity of similar-sized wire used in other circuits, so the different sizes will be as few as possible.

If a feeder supplies more than one set of mains, the drop in the sub-feeders must be calculated and added to the other calculations for feeders and mains.

When calculating for loops, it is only necessary to allow for a length equal to one-half the length of the loop; that is, if the loop is 200 double feet, each side of the feeder would be 100 double feet or 200 single feet, or allowing for an average length, it would be 100 single feet, or half the total length of the loop. The current for each 100 single feet would be half the total current carried by the feeder.

The calculations above are based on a unit of resistance at 75° F. and if the temperature increases above that limit, the resistance will also increase, causing an increase in the drop, but usually there is sufficient margin not to exceed the 3 per cent allowed.

This calculation for drop shows why lamps that require a lower voltage to produce their standard candle-power should be placed far from the generator, and those that require higher voltage near the generator where the drop is least.

In calculating the drop in power circuits, it is usual to allow a little greater drop, for here drop is not of so much importance, 5 per cent usually being allowed, and of course all the drop takes place in the feeder from the switchboard to the motor panel, making the calculation very simple.

In the following examples, take the resistance of 1 foot of copper wire 1 circular mil in diameter to be 10.78 ohms.

Problems on Size and Drop in Wires.

1. A motor receives 100 kilowatts of power at a distance of 10 miles from a generator, and takes a current of 20 amperes. The loss in the wires is to be 10 per cent of the generator output. Find (1) the voltage at the motor, (2) at the generator and (3) the diameter in mils of the line wires.

Ans. 1. 5000 volts.
2. 5555.5 volts.
3. 202.5 mils.

2. A feeder from a generator whose voltage is 110 volts is 100 feet to its feeding center. On one side of the feeding center it supplies a motor that takes 30 amperes and is 300 feet away. On the other side, it supplies 40 incandescent lamps each taking .5 ampere and grouped 200 feet away, and beyond these two arc lamps in series. Allowing 2 per cent drop in the feeder, calculate the size necessary. If the size of the wire supplying the lights is 33.332 circular mils, find the voltage across each arc lamp. Calculate the size required for the motor mains, allowing 5 per cent drop.

Ans. 1. 53.900 cir. mils.
2. 52.28 volts.
3. 36.000 cir. mils.

3. What size wire is required to deliver current at 110 volts to a motor of 10-H. P. output and 80-per cent efficiency. The E. M. F. of the generator is 125 volts and the motor is 500 feet away.

Ans. 60.943 cir. mils.

CHAPTER XXVII.

WIRING.

The wiring of all ships in the navy presents peculiarities, though as a rule it all follows one general system. The distribution of the current in ships in commission for lighting and power purposes varies according to the size and class of ship, and to a certain extent on the time of the installation. The principal modifications in the wiring from time to time are intended to effect saving of current and at the same time equalize the general "drop" or fall of potential around the different circuits.

In the early days of application of electricity to vessels, the distribution of current was a comparatively simple matter, as electric lighting was the only consideration, but the demand for current for power has increased at such a rate that the general question of supply and distribution is one that depends almost wholly on power, the lighting current forming only a small percentage of the whole.

Circuits.

There are three classes of circuits, each being entirely separate and distinct from the others. They are named:

(1) **Search-light circuits.**
(2) **Lighting circuits.**
(3) **Motor circuits.**

Search-Light Circuits.—Each search-light has a separate feeder leading from the dynamo-room, from the search-light panel, through a double-pole fused switch, rheostat, ammeter and double-pole automatic circuit breaker direct to the terminal in the search-light pedestal. Each search-light has its own voltmeter on the search-light panel.

Lighting Circuits.—The lighting system is divided into two divisions, each division having separate feeders and separate mains:

(1) **Battle service.**
(2) **Lighting service.**

The **battle service** includes every light installed below the protective deck and every light above the protective deck whose use is necessary when the ship is in action. This includes lights for operation of guns, at ammunition hoists, at boat cranes, at controllers, in military tops, on search-light platforms, in conning-tower, in turrets, lights in chart houses and pilot house, all signal and running lights, binnacle lights, instrument lamps, at blowers above protective deck and in passageways and compartments used in time of action.

The **lighting service** includes all lights not on the battle service, lights intended for general illumination in living spaces, passageways, offices, store-rooms and cabins.

Motor Circuits.—Motors whose normal full-load working currents are less than 50 amperes are grouped on the same feeder, but no feeder shall have a load in excess of 100 amperes.

Each motor whose normal full-load working current exceeds 50 amperes is fed by a separate feeder with the exception of motors in turrets, where motors for the rammer, elevating and ammunition hoist are usually on the same feeder. The feeders are unbroken, except very long lengths, which are broken in feeder boxes for ease in testing.

General Plan of Wiring for Lighting Circuits.

The wiring plan in general use is that known as the **two-wire feeder** system. Each circuit is complete in itself through each lamp and through the source of supply. This system is in contrast to that using one wire with a common return through the body or framework of the ship.

The **feeders** are the conductors that lead from the switchboard or distribution boards direct to their feeding centers, and they supply or feed currents to the mains. If of short lengths, the feeders are unbroken from the switchboard to their feeder centers, but if of long lengths they are broken in feeder junction boxes, for the purpose of testing or ease in installing. No lights are taken from the feeders.

The **mains** are the conductors that run in the vicinity of the places to be lighted, and are fed by the feeders. The mains are

broken at such places where lights are to be taken off by means of junction boxes, and from these junction boxes, conductors are run to the lamps. These small conductors from the mains to the lamps are called **branches.**

A **bus feeder** is a feeder that runs from a switchboard to a distribution board, feeding current to the bus bars on the latter.

A feeder may supply one or more mains, the branches of the feeders then being called **sub-feeders.**

Long lengths of mains are undesirable and should be avoided where possible, but it frequently happens these have to be installed along the upper decks and in passageways. These long lengths suffer considerable drop of potential due to their resistance, and the lamps at places far from the feeding centers consequently burn dimmer than those nearer the source of supply. (This assumes that the lamp gives its rated candle-power at the standard voltage.) This is remedied somewhat by using at the far ends of the mains, lamps which require lower voltage to produce the standard candle-power.

Loop System.

In order that all lamps on a circuit shall burn with equal brilliancy at all times, it is necessary that the resistance of the circuit from the generator to any lamp shall have a constant value, and be equal to the resistance through any other lamp. This is partly accomplished in the ordinary **tree** system of wiring, but is much better done in the **loop** system, in which the mains are run in the form of closed loops.

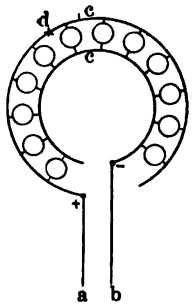


FIG. 285.
Loop Wiring.

An ordinary loop is shown in Fig. 285, *a* and *b* representing the feeder and *c, c,* the mains with the lights taken off between them. An inspection of this loop will show that the distance the current has to flow from the + terminal to the — terminal for any one lamp is the same as for any other lamp, hence the resistance is the same and consequently the fall of potential is due to the same resistance, and all having the same voltage will burn with equal brilliancy.

This loop has the disadvantage of not furnishing current to all the lamps in case of a break in a main. If there was a break at *d* in the positive main, all the lights to the right of the fracture would be extinguished. This disadvantage does not exist in the next loop, though it is not as perfect for equalizing the drop.

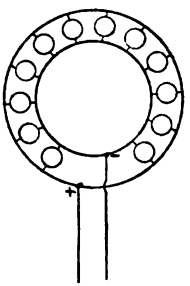


FIG. 286.
Loop Wiring.

In the loop shown in Fig. 286 it is seen that in the event of a fracture in either leg of the circuit, there will be no break in the continuity of the circuit and all lamps will still burn, and it would require two breaks in any one leg to extinguish a lamp. This is a very ordinary form of loop installed on shipboard, usually being provided with an interconnecting switch opposite the junction with feeder.

Still another modification of the loop system is shown in Fig. 287.

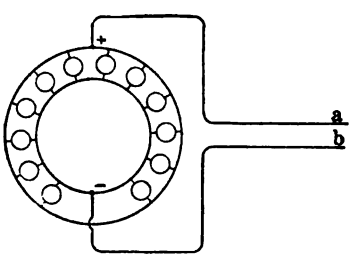


FIG. 287.—Closet Wiring.

This is known as the **closet system,** but it does not adapt itself very readily for installation on board ship, though instances of its installation are known. It combines the advantages of both the other loops, and as a means of equalizing potential it is almost perfect.

Simple Parallel System.

Outside of the loop system, the general plan of wiring is that of the simple parallel system, as shown in Fig. 288.

The feeders are *a* and *b*, feeding the mains *c* and *d* from which are taken in simple parallel, the lights *e, e.* Every light is taken direct from the mains and that is the general rule, though in some cases, there are sub-mains from the principal mains, and lights taken from these sub-mains as though from the principal mains. To the right of the figure is shown a sub-main *g, h,* from *c, d* and the lights *e, e* are taken from this sub-main. In this system, the

feeders are brought to a point where the mains will divide the current equally, as a rule feeding into the centers of the main. To this class of feeders is given the name **center feeders.** If the main is practically but a continuation of the feeder, as it is in isolated cases, it is called an **end feeder.**

This system allows considerable drop along the length of main, but the conductors are made sufficiently large to reduce the drop to a small amount. It frequently happens that the best all around result is obtained by a combination of the two systems. A feeder

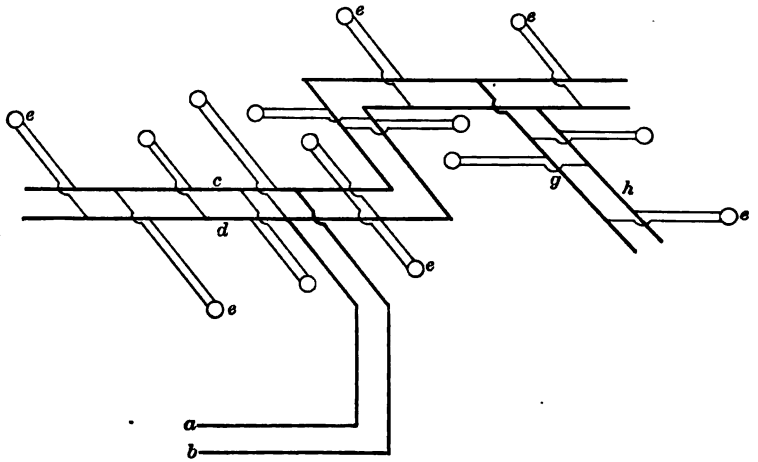


FIG. 288.—Parallel System of Wiring.

may feed two loops, with sub-mains taken from the loop in which the simple parallel system is adopted.

Loops should be resorted to wherever possible, for though it may take more wire in the mains it decreases to some extent the amount used in the branches, and the general equalizing of potential and current all around the circuit far outweighs any other disadvantages.

As an instance of the combination of the loop and simple systems as installed on board ship, Fig. 289 will show a circuit as installed on one of the gunboat class.

There are feeder boxes at *a*, *b*, *c* and *d*. The main feeder from

the switchboard comes direct to *a*, from which run sub-feeders to *b* and *c*. At *d* is a sub-main running aft. These loops are on different decks, the upper loop running entirely around the half deck, through offices, pantries, through and around the cabin. The lower loop makes a complete circuit around the wardroom, through the state-rooms and wardroom country, the sub-main leading aft for lights in store-rooms, and steering engine-room. The sub-feeder supplying the lower loop runs up and down, and such a feeder is sometimes called a **riser.**

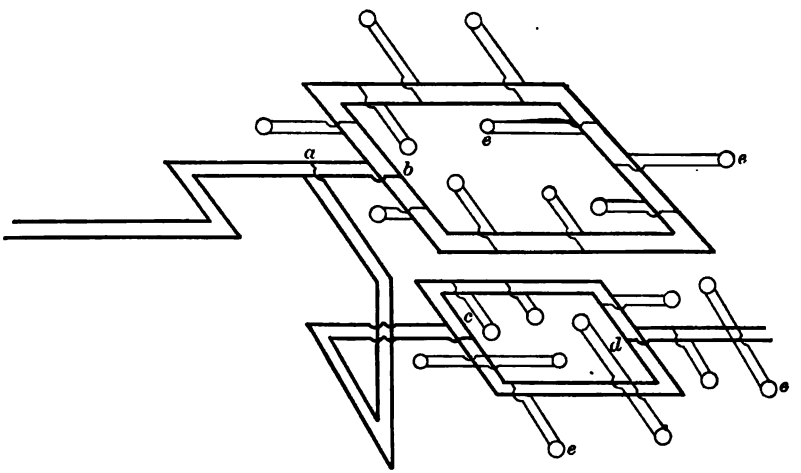


FIG. 289.—Parallel Loop System of Wiring.

This makes a well-balanced combination, in which though there is a drop of potential from the generator, there is not a difference of $\frac{1}{2}$ volt measured in any part of the circuit.

NOTE.—**It might be noted as a point in wiring that in connecting up a closed loop care must be taken to connect the proper terminals, otherwise instead of making two complete loops of the conductors, it may be connected as one long loop of single conductor, a serious combination for the fuses when the circuit is completed.**

Whenever mains for the lighting circuits are led from feeders, it is done through standard junction boxes, having double-pole fuses which blow on the basis of 1 ampere per 500 circular mils of the main.

No more than two feeders are ever interconnected and no feeders are ever interconnected through their mains.

All outlets from the mains are fed by branch wires, fused. In offices and state-rooms two outlets are usually installed on the same branch circuit. Each outlet for magazine lights is run from a separate junction box on the mains.

In the motor circuits when several mains lead from the same feeder at any one point, a small distributing panel is sometimes used, fitted with double-pole fuses, which blow at double the normal current of the motor.

Marking of Feeders and Mains.

As a means of identification of the various feeders and mains installed in a ship, they are marked at certain intervals with letters and numbers according to a plan previously adopted. This is a great help during installation and a still greater help after the plant is completed. The battleship *Connecticut* is designed for distribution with 82 feeders leading to feeding centers from which run 166 sets of mains. As an illustration of the scheme of marking, that employed on the *Connecticut* will be given. The feeders are divided into groups according to the following table, and each group of feders is given a letter (capital), this letter being an abbreviation of the principal service in the feeder group:

Lighting feeders, battle service	B
Lighting feeders, lighting service	L
Search-light feeders	S
Ammunition-handling feeders	A
Ventilation feeders	V
Boat-crane feeders	C
Motor-generator feeders	M
Deck-winch feeders	W
Turret-power feeders	T
Miscellaneous-power feeders	P

Nearly every feeder supplies one or more mains and such mains are designated by the same number which the feeder carries and a small sub-letter. The feeders are numbered consecutively commencing with 1, thus the first lighting feeder, battle service, is B1. There are 11 battle feeders, so the first lighting feeder, lighting service, would be L12, etc.

The feeder B1 supplies eight mains, being designated 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, the letter designating the kind of service being omitted. If there is a sub-main from one of the mains a new series of numbers is added to the signification for the mains. Thus the sub-main from 1b, would be 1b1, etc. Reference to a detailed table shows at a glance the nature and location of any main.

Wiring Installation.

The general requirements of wiring installation change from time to time, but the instructions given under this heading are those at present ordered by the Bureau of Equipment in the Standard Specifications.

All wires for feeders, mains and branches are installed in enameled steel conduit, except in wing passages, main generator and equalizer cables and feeders from switchboard to dynamo-room bulkheads, which may be run in iron-strapped insulators, the wire in the insulators to be protected from mechanical injury by a metal covering of sheet or galvanized iron.

Thorough water-tightness is observed for all leads into wiring appliances and fixtures, through all bulkheads leading into or out from a water-tight compartment and through all decks.

Where conductors on lighting circuits are connected in fixtures and wiring appliances, the outer tape and braid on the ends of the conductors is to be removed, exposing the vulcanized rubber to within $\frac{1}{8}$ inch of the outside of the gland, and special care must be taken not to cut or injure the vulcanized rubber. When the tape and braid is removed for connecting up movable fixtures the braid ends shall be protected from fraying by whipping the ends of the braid and varnishing.

Water-tighting through bulkheads or decks is secured by the use of either of two kinds of stuffing tubes; one form using lamp-wick packing, the other red lead.

All wire run through decks or bulkheads where molding is used is led through standard stuffing tubes, and when water-tightness is not required, the wires are led through holes bushed with hard rubber.

No feeders or mains are led overhead in places subject to great heat, or through or into coal bunkers if it can be avoided.

Installation of Conduit.—The conduit containing the conductors is secured to the metal of the ship by stout straps which in the case of bulkheads are secured by machine screws. To attach conduit to beams, stiffeners and the like, a clamp is used of a design that does not require the beam to be drilled. All conduit is to be continuous and where passing through water-tight bulkheads, the conduit must be made water-tight by standard stuffing tubes.

Where conduit passes through armor, a hole is first drilled and a long nipple inserted, water-tightness secured by jam-nuts on the nipple, each side of the armor, set up tight against the armor. The conduit is connected to the nipple on each side by a coupling or union.

Lengths of conduit are ordinarily connected by means of unions, but in some cases, running threads are used, in which case the thread is fitted with an extra half coupling which screws down against the full coupling, acting as a lock-nut. The ends of the coupling and half coupling are slightly reamed, filled with lamp-wick packing and the whole joint treated with red lead.

Conduits for *magazines* are made of seamless drawn brass, and this is also required for all leads within 12 feet of the *standard compass.*

Both positive and negative legs of the same circuit are led in the same conduit for all conductors of and below 60,088 c. m. All conductors above this size have a separate conduit for each leg, the lengths of conduit for the same circuit being kept as close together as possible.

Installation of Molding.—This is authorized in certain places, and when installed consists of three pieces; the backing strip, molding and capping.

The *backing strip,* secured first, is secured by brass machine screws, no screws coming under junction boxes, switches or receptacles and all screws are countersunk. *Molding* is secured by countersunk screws through the center wall to the backing strip. Both backing strip and molding is treated with white lead before

being secured together. The capping strip is secured to the molding by round-head screws to the side walls of the molding.

All wiring accessories shall be separated from the metal of the ship by at least ¼ inch of clear solid wood, and they are never located over screws securing the backing in place. No double conductor or twin conductor is used with molding.

Systems of Distribution.

It is very evident that no standard method or system of distribution can be designed that will be suitable for all sizes, classes and designs of vessels, and each ship or at least each class will have peculiarities which distinguish it from others of different classes. It is a different matter distributing 10 electrical horsepower in a gunboat of 1000 tons from distributing 1000 electrical horsepower in a battleship of 16,000 tons. The switchboard and fittings, such as bus bars, switches and fuses, that would distribute and protect 100 amperes would not serve the same purpose for 7200 amperes, the current delivered by the generators of the latest battleships. It is not proposed to go into the details of the different methods in use in different ships, but an illustration of extreme types will serve to show the radical differences, and emphasize the importance of learning at once the system of the ship to which one may be attached.

Gunboat Distribution.—As an illustration in this type of vessels, one of those at present in commission may serve. This vessel has two units, each unit consisting of a generator (engine and dynamo) of 4-kilowatt capacity, the generators wound for 80 volts, installed in the same dynamo-room. Current from each generator is led to a small switchboard, where there are two 3-pole generator switches connecting to the bus bars on the back of the board and to the equalizing bar for connecting the machines in parallel. From the bus bars, the different sections, about ten in all, lead off to different parts of the ship. Each circuit is protected on the switchboard by two pole fuses.

On the same switchboard there is one voltmeter with 2-point switch for registering the voltage of either dynamo, one ammeter for each machine, one field regulator for each machine, and one

lamp ground detector with 2-point switch. On a separate panel for the one search-light is one voltmeter, one ammeter, one circuit breaker and one 2-pole double-throw switch for use with either machine.

Battleship Distribution.—As an illustration of the general distribution in this class of vessels, the *Louisiana* or *Connecticut*, may serve.

There are eight generators of 100-kilowatt capacity each, the generator wound for 125 volts, or a maximum rated capacity of 6400 amperes. Four of these generators are installed in a dynamo-room in the fore part of the vessel and four in another dynamo-room in the after part of the vessel. In each dynamo-room there is a generator switchboard capable of controlling the four units. Each unit has a circuit breaker, voltmeter, ammeter, field regulator and switches for connecting to the lighting bus bars, to the power bus bars and to the equalizing bus bar and common negative bus bar.

For each main generator board there are two feeder panels, one for lighting and one for power. The power feeder panel contains two 2000-ampere single-throw double-pole switches, to control the power current to each of two distribution boards to be described later; two 2000-ampere double-pole circuit breakers, one in the line to each distribution board, and one 2400-ampere meter to record the entire power current from each dynamo-room. The lighting feeder panel contains two 500-ampere single-throw double-pole switches, to control the lighting current to the distribution boards; two 500-ampere double-pole circuit breakers, one in the line to each distribution board, and one 800-ampere meter to record the entire lighting current from each dynamo-room.

In addition to the main generator switchboards there are two distribution boards, located one adjacent to each dynamo-room, but separated therefrom by water-tight bulkheads. On each distribution board there are two sets of bus bars, one for lighting and search-lights, and the other for all power circuits. Either set of bus bars on either distribution board is capable of being energized from the feeder panels of either generator board.

Each distribution board is composed of three panels, a lighting (including search-lights) panel, a power panel and a turret panel.

Each lighting panel contains a 500-ampere double-throw double-pole switch for taking total panel load from either dynamo-room; a double-pole fused switch for each lighting circuit (eleven from each board), a double-pole circuit breaker, a regulator and an ammeter for each search-light circuit (three from each board), a voltmeter with 3-point switch for the search-light circuits, an ammeter to measure the total current on the panel, and a voltmeter with 2-point switch for measuring the voltage of the lighting bus feeders from either dynamo-room.

Each power panel contains one 1500-ampere double-pole double-throw switch for taking total panel load from either dynamo-room, one double-pole single-throw switch for each power circuit (seventeen from for'd board, nineteen from aft), and an ammeter to measure the total current on the panel.

Each turret panel contains one 1500-ampere double-pole double-throw switch for taking total panel load from either dynamo-room, one double-pole circuit breaker for each turret circuit (twelve on each board), an ammeter to measure the total current on the panel and a voltmeter with 2-point switch for measuring the voltage of the power bus feeders from either dynamo-room.

Ground detectors, one each of instrument type and lamp type, are installed on each distribution board.

In each turret is located a distribution panel containing a double-pole double-throw switch for receiving current from either distribution board and other devices for controlling the motors in the turret in which the panel is placed, including ammunition-hoist motors, elevating motors and loading motors.

In each barbette is located a control panel with instruments for controlling the motor generator for each turret, and all appliances for the circuits both on the motor and generator side.

The Protection of Circuits.

Mention has been made of circuit breakers and fuses in the preceding description of current distribution, and their use and action will now be considered.

Fuses.—This is a name given to two entirely different devices, both, however, depending upon the heating effect of an electric

current, one being used to fire electric explosives and the other to protect electric circuits against excessive heat. The last, or **safety fuse**, as it is commonly known, is the one under consideration. This is an appliance placed in an electric circuit, designed to carry the ordinary amount of current but to melt and break the circuit if the current becomes great enough to heat any other part of the circuit to a dangerous degree. It is made of such material that its resistance is higher than an equal length of the rest of the circuit. As the heat developed is C^2Rt joules, C being the current, R the resistance and t the time, it follows that the fuse is always at a higher temperature than the rest of the circuit, and on account of its low-melting point, any increase above the ordinary current will raise the temperature to its melting point and melt it.

The **requirements** of a fuse are that it should melt at a comparatively low temperature, that it should melt quietly, that it should have hard terminals, and that it should be long enough to prevent an arc being maintained after the fuse is melted. There should be no reddening or excessive elongation when the current is slowly carried up to the fusing point.

The **substances** generally used are lead, or an alloy of lead and tin, called "half and half" solder. Sometimes bismuth is added to lower the temperature of the melting point, and sometimes copper is used alone where there is no danger from flying sparks.

Fuses are *rated* according to the number of amperes taken normally by the circuit they are to protect. A 10-ampere fuse is intended to protect a circuit whose regular current does not exceed 10 amperes, but it should not burn at 10, but at a value higher than this. By a 10-ampere fuse is meant one that will at least carry that much current. The rated capacities are 10, 15, 20, 30, 40, 50, 60, 75, 100 amperes and the rated capacity is stamped on the face of one of the tips. Generator fuses are rated higher.

Calculation of Sizes for Fuses.—The current that can be carried depends on the diameter of the fuse and not at all on its length, as will be shown.

The number of joules produced by a current C in a resistance R in a time t is

$$C^2Rt.$$

Under the subject *resistance,* it was shown that

$$R = \frac{\rho l}{a}$$

where

ρ is the specific resistance of the substance,
l is the length of the substance,
and a is the area of cross-section.

If the conductor is round

$$a = \frac{\pi d^2}{4}$$

or the number of joules in time t becomes

$$\frac{4C^2\rho lt}{\pi d^2} \tag{1}$$

If ρ is expressed as the resistance per cubic centimetre or rather the resistance of a conductor one centimetre long and one square centimetre in cross-section, then l and d must be expressed in centimetres.

The amount of heat radiated from the fuse depends on the material, on the initial temperature, on the melting point, on the surface available for radiation and on the time.

The surface of the fuse is

$$\pi dl \text{ sq. cm.} \tag{2}$$

If the radiation per square centimetre per degree rise of temperature per second is known, the total amount radiated becomes known. For lead this is about .001 joule, or the total amount of heat radiated in time t, till the melting point is reached,

$$.001\pi dlt(T - T'). \tag{3}$$

T = melting point,
T' = original temperature of fuse.

When current flows through the fuse, if the heat is not radiated as fast as produced by the current, its temperature will rise, and at any time if radiation equals that produced, the temperature will remain stationary. If not, the temperature will go on increasing until the melting point is reached, and just at that instant it can be assumed that the number of joules produced by the current is

equal to the radiation from the fuse, which it would be if the temperature remained stationary at the melting point. C could have such a value that this condition could exist, and any slight increase in C would destroy the equilibrium. At the instant (1) = (3) or

$$\frac{4C^2\rho lt}{\pi d^2} = .001\pi dlt(T - T'),$$

an expression both independent of the length l of the fuse or the time t, as they are both common factors. Solving for d, we have

$$d^3 = \frac{4C^2\rho}{\pi^2.001(T - T')}$$

in which all values are known and d may be calculated.

A rule for finding the diameter of a fuse is given similar to the above

$$d = \left(\frac{C^2}{K}\right)^{\frac{1}{3}}$$

where

C = current in amperes,
d = diameter in inches,
and K = a constant, depending on the material.

For lead $K = 1379$, and for half and half solder $K = 1318$, and for copper $K = 10{,}244$.

Multiple Fuses.—Two fuses in multiple will carry twice as much current as one if they are in all respects alike, and so placed that the heating of one does not affect the other. Two fuses twisted together will not carry as much current as if they are apart, for the radiation in the twisted fuse is less and consequently the temperature will be raised quicker.

In making multiple fuses to carry a desired load, the factor, length, enters into the calculation, for different currents are to be carried, and the fall of potential being the same, the currents are proportional to the lengths. The absolute lengths of the fuses are not required but they must bear a certain ratio to each other.

Suppose it was desired to make a copper fuse to protect a current of 250 amperes, by a No. 14 B. & S. copper wire. This size copper will carry 166 amperes before fusing, leaving the difference 84 amperes to be carried by another fuse in multiple. The cross-

section and specific resistance being the same, $R : R' :: l : l'$ and the fall of potential being the same, $CR = C'R'$, or

$$R : R' :: C' : C$$
$$R : R' :: l : l'$$
$$\therefore \quad C : C' :: l' : l$$
$$\text{or} \quad \frac{166}{84} = \frac{l'}{l}.$$

If one fuse is made 1.66 inch in length, the other must be .84 inch or some proportion of these values.

Fuse Shapes.—The fuses for non-water-tight receptacles, wall socket or receptacle plugs are of plain fuse wire of 3-ampere capacity. The fuses for branch junction boxes are of the copper-tipped glass-tube type. The fuse wire is enclosed in a glass tube fitted with copper tips, to which the fuse wire is soldered. The fuse goes through small holes in the copper tips, the latter being cemented to the glass tube. The capacity of the fuse is 3 amperes.

The circuit fuses on the switchboard are of commercial copper-tipped pattern with slots in tips at right angles to each other. The length of fuse wire must be at least 1 inch. These fuses are ribbon-shaped.

Fuses for generator circuits are of commercial copper-tipped pattern, 2½ inches from center to center. These are ribbon-shaped, half circular in form. Rated capacities of dynamo fuses are 25, 50, 75, 100, 200, 300, 400, 500. The rated capacity is stamped on one of the lugs.

When a circuit requires a fuse larger than 100 amperes, a generator fuse is used.

When a generator fuse greater than 500 amperes is required, two fuses of equal capacity are mounted in parallel.

Fuse wire or wire from which fuses are made is furnished on spools, wound like cotton, for convenience in cutting off any desired length. It is generally in spools of 3, 10, 20, 40, 60 and 100 amperes, above which, completed fuses are used.

Circuit Breaker.—The function of this piece of apparatus is well defined by its name, being a contrivance to break a circuit in case the current rises above a certain fixed value, acting for the same purpose as an ordinary safety fuse; to interrupt a circuit before

the current becomes so great as to become dangerous on account of the heat produced.

They are placed directly in the circuit to be protected and consist of a double-pole switch which when closed is held in place by a trigger against the tension of a very strong quick-acting spring. In the circuit on the breaker is an electromagnet surrounding an iron core which, as the magnet is energized by the current, is pulled into the hollow of the coil, the amount of the pull depending on the current. As the core is attracted, it is arranged to trip a release trigger, which releases the catch holding the spring, and the latter throws out the switch arms, breaking the circuit. The current for which the release may be effected may be varied by moving by hand the position of the plunger before current is turned on. A small index shows for what current the breaker is set, that is, for what current the switch arms will be released.

Circuit breakers are placed in circuits that are liable to a sudden fluctuation in current, and in currents too great to be protected by ordinary safety fuses. If fuses were placed in search-light circuits, they would be continually melting owing to the high rise of current at intervals and necessitating constant renewals, an operation requiring much care and practice. When the circuit is broken by the circuit breaker it is only necessary to throw it in again by hand, the work of an instant. They can be used in the place of ordinary switches in circuits carrying heavy currents, for they can be operated at will by hand and have the advantage of automatically opening in case of any sudden rise in current.

The contact pieces, both on the switch arms and on the base of the switch, are made of block carbon, the carbons pressing against each other when the circuit is closed. This prevents the contacts from being burned away by the arc formed in breaking, which would soon be the case if they were of copper, on account of the low-fusing temperature of copper.

In some forms of circuit breakers, the switch arms are made to act independently, each having its electromagnet device and tripping mechanism.

Location of Fuses and Circuit Breakers.—Every precaution is taken in ship installation to guard against excessive currents,

whether from short circuits, grounds, leaks or whatever cause. Every part of the installation is protected, each main generator, each circuit, each motor, or motor generator, each search or arc light and each individual incandescent lamp. There are main fuses or circuit breakers on the main switchboard to protect the generators, each lighting or power circuit is protected on the switchboard and each lamp on a circuit and each motor is separately protected. The fuses for the incandescent lamps are placed in the junction boxes from which the branches are led. In certain places like the engine or fire-rooms, where the junction boxes would be likely to be installed in inaccessible places, they give way to distribution boxes, which are practically combinations of ten or twelve junction boxes, all the branches leading from these boxes. They are installed in accessible places, where all the fuses can be readily examined or replaced. As an illustration of the protection given, that from a generator to a small portable ventilating fan may be cited. There is the main fuse or circuit breaker between the generator and main switchboard, then if there is a distribution board, there is a fuse between that and the main switchboard. The circuit on which the fan is installed is fused on the bus bar of the distribution board. At the junction box from which the fan leads there is a fuse. From the junction box the conductor leads to a receptacle which contains a fuse, and into this screws the plug from which leads the double conductor to the fan. This plug is also fused, making six fuses or circuit breakers in all between the generator and the fan, the safety appliances, of course, decreasing in size as the current falls off from that of the main generator, possibly 800 amperes, to that of the fan, .8 ampere.

Three-Wire System.

Before leaving the subject of wiring, brief mention will be made of the three-wire system, which has been installed on two of our battleships, the *Kearsarge* and *Kentucky*.

In this system, two generators are used, being connected in series, as indicated in Fig. 290, *a* and *b* representing the terminals of the two machines, the negative terminal of *a* being connected to

the positive terminal of *b*, and from this connection a third wire leads out from the machines, following the lead of the outside mains *c* and *d*.

The lights are not taken directly from the mains leading from the machine or switchboard, but from mains fed by feeders as usual in the feeder system, but the above illustration is made to illustrate the principles involved.

The three mains run along together throughout the part of ship to be lighted, and as nearly as possible an equal number of lights is taken from each side; that is, from the outside positive to the middle or neutral wire, and from the outside negative to the neutral wire.

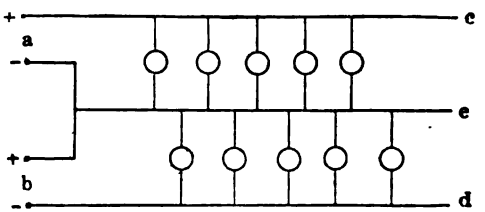


FIG. 290.—Three-Wire System.

The generators being in series, the difference of potential from *c* to *d* is twice that from *c* to *e* or of one generator. The effect of having practically two lamps in series, when one on each side of the neutral is burning, is to have a double E. M. F. and a double resistance, so the current through each is the same as though it were connected up on the ordinary two-wire system, with the E. M. F. of one machine and the resistance of one lamp. The result of this combination is to give the same current, consequently the same light, with the saving of one length of conductor.

If there were an equal number of lamps on each side of the neutral burning, it is evident that the neutral wire would have no current at all, from which fact it derives its name, neutral. If there are an unequal number of lamps burning on the two sides, the neutral wire would carry the current which represented the difference between the total current on one side and the total current on the other. It is presumed that at least half as many lamps

on one side would be burning as on the other, and it is the general practice to make the neutral wire of half the carrying capacity of the two outside wires. If, however, it is contemplated at times to use one generator as on the two-wire system, then the neutral wire would necessarily have to be of the same size as the other wires.

Using one generator on the two-wire system detracts somewhat from the advantages of this system, one of which is the saving effected in the copper. To give the same illumination, two generators running in the three-wire system effect a saving of about three-eighths of the total copper used in the mains compared with that used with two generators on the two-wire system. If x represents the cross-section of the outside wires, and is used as a measure of their carrying capacity, the total wire used with the two generators two-wire system would be represented by $4x$, and on the two generators, three-wire system by $2\frac{1}{2}x$, or a saving of $1\frac{1}{2}x$ or $\frac{3}{8}$ of $4x$, the total amount. Where large areas are to be illuminated, this saving in copper would be considerable, but the saving is considerably reduced if the two-wire system is to be used, as is the case on shipboard.

The other principal advantage of this system, as used on shipboard, is the increased E. M. F.; from the standard voltage of 80 as installed on those ships, there is available 160 volts for use on fast-running motors. The voltage from one outside to the neutral can be used for the slow-speed motors, and from the two outsides for the fast speed ones, or combinations can be made, the fields being excited either by one or the other, and the armature current taken with either voltage.

Example of Three-Wire Circuit.

In a three-wire system, with 160 volts between the outers, the load on the positive side consists of 40 5-c. p. lamps, 40 16-c. p. lamps and 8 32-c. p. lamps; on the negative side the load is 20 5-c. p. lamps, 60 16-c. p. lamps and 6 32-c. p. lamps. What is the magnitude and direction of the current in the neutral wire? Each lamp requires 3 watts per candle power.

If the neutral becomes disconnected from the generators, what is the voltage across each set of lamps?

Ans. **3.35 amperes, away from machines.**
83 volts across + side.
77 volts across — side.

CHAPTER XXVIII.

WIRING APPLIANCES AND FIXTURES.

Wiring appliances are of three general classes: **conduit wiring appliances, wiring appliances (water-tight)** for use with molding and **wiring appliances (non-water-tight).**

In general all wiring appliances consist of a cast composition box, a sheet-brass cover, a sheet-rubber gasket (for water-tight appliances) and an interior fitting on a porcelain base.

Standard Conduit Wiring Appliances.

Junction boxes:

Feeder,
Main junction,
3-way branch,
4-way branch.

Switches:

5-ampere single-pole,
5-ampere single-pole with hood,
25-ampere double-pole,
50-ampere double-pole,
100-ampere double-pole,
50-ampere double-pole, double-throw.

Receptacles:

5-ampere,
5-ampere with hood.

Combination switch and receptacle:

5-ampere,
5-ampere with hood
25-ampere,
25-ampere with hood.

Distribution boxes:

8-way,
12-way.

Water-tight boxes:

For 1½-inch conduit,
For 1¼-inch conduit,
For 1-inch, ¾-inch, and ½-inch conduit.

Standard Appliances for Molding (Water-Tight).

Junction boxes:

Feeder,
Main,
3-way branch,
4-way branch.

Switches:

5-ampere single-pole,
25-ampere double-pole,
50-ampere double-pole,
100-ampere double-pole,
50-ampere double-pole, double-throw.

Receptacle:

5-ampere.

Combination switch and receptacle:

5-ampere,
25-ampere.

Standard Appliances (Non-Water-Tight).

Switch.

Receptacles:

Key,
Keyless,
Porcelain base.

Sockets:

Key,
Keyless,
Instrument lamp.

In addition the general term "wiring appliances" also includes *fuses, gaskets, stuffing tubes, box tubes, terminal tubes, conduit* and *molding.*

Conduit Wiring Appliances.

All boxes for conduit wiring consist of a cast composition, box shape, fitted with a brass cover through which is a hole covered by a screw cap. Cover is secured to box by screws through a sheet-rubber gasket. The interior fittings rest on a porcelain base, secured to the bottom of the box through sheet mica. The sides and ends of the boxes are bossed and are threaded to receive the conduit according to the use for which the box is intended. The boxes are fitted with lug feet by which they are secured in place by screws.

Junction Boxes.—These are of two sizes, the smaller used when wire is 30,000 c. m. (twin conductor) or smaller. They are fitted for conduit connection on both ends and sides.

Feeder Junction Box for Double Conduit.—These are used when wire size is in excess of 60,000 c. m. (twin conductor) and each leg of circuit is run in a separate conduit. These boxes are used for wire sizes up to 157,563 c. m.

5-Ampere Switch, Single-Pole, Box.—Fitted to be inserted in the conduit line, and to take either ½ or ¾-inch conduit, with a maximum wire size 9016 c. m. (twin conductor). Box cover fitted with switch stem, the stem made water-tight by stuffing-box, packing ring and gasket.

25-Ampere Switch, Double-Pole, Box.—Fitted to take 1-inch conduit with maximum wire size of 30,000 c. m. (twin conductor). Fitted with screw cap over switch when not in use.

50-Ampere Switch, Double-Pole, Single or Double-Throw, Box.—Fitted for 1½-inch conduit, otherwise like preceding box. Box for 100-ampere switch is same as for 50 amperes.

5-Ampere Receptacle Box.—Fitted to take a ½ or ¾-inch conduit, all receptacles being threaded on one side of the box only for connection to the conduit. Fitted with cover for use when receptacle plug is not in use.

5-Ampere Switch and Receptacle Box.—Same as preceding and fitted with switch handle like 5-ampere switch.

25-Ampere Double-Pole Switch and Receptacle Box.—Fitted with two holes, one for receptacle, one for switch, with covers; otherwise like 25-ampere switch.

Distribution Boxes, 8-Way and 12-Way.—These are large composition boxes, for taking off eight or twelve branch circuits. The ends are threaded for 1-inch conduit, maximum wire size 30,000 c. m. (twin conductor) and the sides for ½-inch conduit for branches, maximum wire size 4107 c. m. The interior fitting consists of a fuse board panel, so arranged that each branch is fused. Fuses used are the same as in the ordinary junction boxes. Current-carrying parts are made of sheet copper, mounted on a slate base, which rests on a hardwood block. The cover has two rectangular holes directly over the fuses, these holes covered and made water-

tight by means of two fuse doors hinged together. The arrangement is such that the fuses may be examined or replaced by opening one fuse door without removing the cover.

Water-Tight Boxes.—These are used to water-tight the inside of conduit. Each size of conduit requires special size stuffing tube. The inside diameter of all tubes is identical with inside diameter of conduit.

Molding Wiring Appliances.

All wiring boxes are cast from composition metal with certain standard dimensions, and fitted with covers of sheet brass, which are secured to the boxes by screws through a gasket of 2-ply cloth insertion sheet-rubber packing. All except main junction boxes, which have plain covers, have a hole in the center of the covers, to which nipples are secured on which screw threaded caps.

All wires entering these appliances do so through stuffing tubes, placed on the sides or ends of the boxes. These tubes are of two sizes, one called large size, the other small size. The maximum wire size for the large size is 157,563 c. m. and for the small size 50,000 c. m. These stuffing tubes consist of the tube proper secured to the box, a screw gland screwing down on a gland washer stamped from sheet brass which in turn presses on a conical rubber gasket, making a water-tight joint between the tube of the box and the insulation of the wire.

Main junction boxes are fitted with two large stuffing tubes in each end.

Feeder junction boxes are fitted with two large stuffing tubes in each end and two large stuffing tubes in one side.

Thre-way junction boxes are fitted with two large stuffing tubes in each end and two small stuffing tubes in one side.

Four-way junction boxes are fitted with two large stuffing tubes in each end and two small stuffing tubes in each side.

5-Ampere Switch, Single-Pole, Box.—Wires are led into box through two small stuffing tubes in each end. Is fitted with 1-inch hole in cover for switch stem, which is fitted with a stuffing-box, packing ring and gasket. A water-tight cap screws down over stuffing-box.

25-Ampere Switch, Double-Pole, Box.—Wires are led into box through two large stuffing tubes in each end. The cover has a 1-inch hole over switch handle, covered by a water-tight cap, which is removed when shipping handle for operation of switch.

50 and 100-Ampere Switch, Double-Pole, Box.—Wires are led into box through two large stuffing tubes in each end and the same on one side. Cover is fitted as for 25-ampere switch.

50-Ampere Switch, Double-Pole, Double-Throw, Box.—Wires are led into the box through two large stuffing tubes in each end and the same on one side. In all other respects they are like the 50-ampere box.

5-Ampere Receptacle Box.—This is in all respects like the 5-ampere switch box except in hole in cover, which has a cap fitted as in the 25-ampere switch, double pole.

5-Ampere Switch and Receptacle Box.—This is in all respects like the 5-ampere switch box, single pole, excepting cover, which has an additional hole fitted as in the 25-ampere double-pole switch.

25-Ampere Double-Pole Switch and Receptacle Box.—This is in all respects like the 25-ampere switch, double pole, excepting cover, which has two additional holes for single-pole receptacle plugs. All holes are fitted with caps the same as for the 25-ampere switch, double-pole box.

All the above boxes are made according to standard dimensions which differ for each class of box.

Interior Fittings.

The interior fittings for all wiring appliances of a similar name, whether for conduit or molding, are identical. All consist of copper-carrying conductors secured to porcelain bases which are screwed to the bottom of the boxes, a layer of mica being interposed between the porcelain and metal of the box.

For **feeder boxes** they consist of double-pole conductors, fitted for one branch. Branch is fused with copper-tipped commercial fuses, and in addition is fitted with copper connecting strips to bridge fuse gaps when desired. Fuses are fitted on mica cups clear of the conductors. Binding strips are large enough to take wires as large as 157,563 c. m., navy standard.

For **main junction boxes** they consist of double-pole, double-branch conductors, fitted for two branches. Fuses are in glass tubes with circular metal tips, secured by spring clips. Binding strips are large enough to take wires as large as 60,000 c. m., navy standard.

For **5-ampere switch, single-pole, boxes** they consist of double-pole conductors, with one broken by a switch, the handle for which is on the outside of box. Switch is quick break with contact springs of phosphor bronze. Binding strips are large enough to take wires as large as 9016 c. m., navy standard.

For **75-ampere switch, double-pole, boxes** they consist of double-pole conductors, both broken by switches, which are quick-break with contact springs of phosphor bronze. Switch is fitted without a handle, but operated by a standard wrench. Binding strips are large enough to take wires as large as 60,000 c. m., navy standard.

For **50-ampere switch, double-pole, boxes** they consist of the same general design as the 25-ampere switch, but with strips large enough to takes wires as large as 157,563 c. m., navy standard. The fittings for the 100-ampere switch, double pole, are the same with exception that conductors are larger.

For **50-ampere switch, double-pole, double-throw, boxes** they consist of double-pole conductors, both broken by quick-break switches, double pole, in order to make contact from a pair of side wires to either pair of end wires. Switch is operated by wrench. All parts are large enough to carry 40 amperes without perceptible heating.

For **5-ampere receptacle box** they consist of double-pole conductors, one end of each fitted to receive the wires, the other end of each secured to phosphor bronze clips for securing receptacle plugs. One end of these clips is secured to the conductor, the other is free. Binding strips are large enough to take wires as large as 9016 c. m., navy standard.

For **5-ampere switch and receptacle boxes** they consist of fittings the same as for the 5-ampere receptacle with the following exception: One leg of the conductor leading to the receptacle is broken by a switch in all respects like the 5-ampere switch.

For **25-ampere combination switch and receptacle box** they con-

sist of fittings the same as for the 25-ampere switch with the following exception: Only one end of the conductors are fitted to receive wires, the other end of each conductor is fitted with receptacle clips like those for the 5-ampere receptacle.

All switches are "on" when the switch handle is lengthwise of the box and "off" when they stand across the box. In those switches turned by a standard wrench, the wrench and end of switch stem are so designed that the former cannot be shipped unless it is put on lengthwise of the box when the switch is "on" and crosswise when it is "off."

Non-Water-Tight Wiring Appliances.

Switches.—The fittings of the switch are mounted on glazed vitrified porcelain, and the switch proper is single pole, snap and quick break, with springs of phosphor bronze. The stem and handle of switch are of metal, and made to turn in one direction only—to the right. Capacity of switch 10 amperes.

Sockets.—The socket proper of key or keyless sockets is made of a close helical spring of 6¼ turns, No. 11 B. & S. phosphor bronze wire, the free end turned to form a small loop. One conductor is secured to this spring, the other to a central contact piece of sheet phosphor bronze. Sockets fit standard 16, 32 and 150-candle-power lamps. The fittings are secured to a porcelain base and covered with a shell of sheet brass made in two pieces. The key for key sockets is of insulating material, usually hard rubber. The circuit for the key socket is broken by a snap arrangement giving a clean, quick break.

Receptacles.—The fittings of the key and keyless receptacles are mounted on round porcelain bases, which are arranged for fusing both legs of the circuit. The socket is of the ordinary commercial type, covered with a brass shell. The key for key receptacle is like the one for the key socket. The porcelain base receptacle is mounted on a porcelain base, the socket the same as the key and keyless sockets with the helical spring. This receptacle is not fused.

Instrument Lamp Socket.—This is for use with instruments as the battle order transmitters. It is of the helical spring type of phosphor bronze wire. Terminals are fitted to take wires as large as standard double conductor 7-22 B. & S. wire.

Conduit.

Conduit consists of the following types:

1. **Steel, enameled.**
2. **Brass, enameled.**
3. **Flexible.**

The steel and brass enameled conduits conform in their metal parts to the dimensions for standard steam, gas and water pipes. They are the following sizes, inside measurement: ½", ¾", 1", 1¼", 1½", 2", with lengths of 10 feet for steel and 12 feet for brass. The enamel is put on in not less than three coats, baked on, inside and out, and is not to be affected by moisture, acids, alkalies or a temperature of 100° C. Sabin's baking enamel is frequently used.

Fittings.—The fittings for steel-enameled conduit are of steel, wrought, malleable or cast iron, for brass-enameled conduit they are of brass or the "beaded malleable" pattern. The following fittings are used with the conduit, steel or brass, conforming to the dimensions of the conduit:

Elbows bent 90° in equal legs, externally threaded on both sides.

Outlet elbows 90°, similar to steam-pipe elbows, both ends threaded internally.

Outlet elbows 45°, similar to above, with both ends threaded internally.

Nipples.—Externally threaded on both ends.

Couplings.—Similar to regular pipe couplings, internally threaded, with both ends right-hand thread, or one end with right hand thread and one with left-hand thread.

Unions.—Similar to regular pipe unions.

Couplings, Reducing.—Similar to regular pipe couplings, internally threaded, right hand.

Plugs.—Similar to regular pipe plugs, right hand.

Bushes.—Similar to regular pipe bushes.

Flexible Conduit.—This is used in sizes of 1", 1¼", 1½", 2", 2¼", 2½", 3" inside measurement. It is made of rubber-lined hose, double cotton.

Molding.

Molding consists of three parts; that part containing the wire gutters is known as the *molding,* the part upon which the molding rests is called the *backing strip* and that which covers the molding is the *capping.*

When run over hardwood surfaces, molding is of the same material and finish as the surrounding woodwork. In all other cases it is of thoroughly seasoned white pine, coated with white lead before being secured in place.

The backing strip is used to cover all rivet and bolt heads, nuts, etc., and to make a smooth surface for the molding.

Molding is made with one, two or three gutters.

Gaskets.

All gaskets used in the various kinds of water-tighting appliances are made of vulcanized rubber compound, containing only pure Para rubber, mixed with mineral matter and sulphur.

The compound contains at least 60 per cent by weight of rubber gum, and sulphur not less than $4\frac{1}{2}$ per cent nor more than $5\frac{1}{2}$ per cent of the weight of the rubber gum. All the sulphur must be combined with the rubber, there being no free sulphur in the compound.

Gaskets are made of eight types, each of which is designated by a letter. They are all of the same general shape, the different types being distinguished by their dimensions. A description of one type is given.

Type A.—The shape is that of two truncated cones of unequal heights joined base to base, diameter top $1\frac{1}{4}$ inch, bottom $1\frac{5}{32}$ inch, diameter of cone bases $1\frac{1}{2}$ inch. The shorter cone tapers from smaller to larger diameter in a height of $\frac{1}{8}$ inch and the larger cone is a height of $\frac{11}{16}$ inch, total length of gasket $\frac{13}{16}$ inch. The gasket is perforated with a central hole the full length of the gasket. The size of the hole is designated by a number signifying the diameter in thirty-seconds of an inch. The numeral zero placed after the letter signifies that the gasket is solid. This type is designated as *A*30, *A*36, *A*0, etc.

In certain forms of gaskets which are made with two or three holes, the designation is by a repetition of the letter as many times as there are holes, followed by a number specifying the diameter of the holes in thirty-seconds of an inch. Thus type *C*, with two holes $\frac{18}{32}$ inch in diameter, would be designated as *CC*18. If more than three holes are used, the word spelling the number of holes is added, followed by the numeral for size. Thus *G* sixteen—8 would mean type *G* gasket, with 16 holes, each $\frac{8}{32}$ inch in diameter.

If a gasket with oval hole is used, the letter is followed by two numerals, indicating the two diameters in thirty-seconds of an inch, thus *C*16-10 would mean a gasket of type *C*, with a hole $\frac{16}{32}$ inch by $\frac{10}{32}$ inch.

FIG. 291.—Single Bracket Fixture.

Fixtures.

Fixtures are referred to as *regular fixtures* and *lanterns*. Regular fixtures are those that are secured permanently in place in various compartments and spaces, and intended for general illumination. They include:

Regular Fixtures.

Bracket light, single or double,
Bulkhead fixture,
Bunker fixture,
Ceiling fixture, No. 1,
Ceiling fixture, No. 3.
Ceiling fixture, commercial,
Deck fixture,
Drop light,
Overhead bunker fixture.

Bracket Light.—The bracket light is used for side lighting in officers' quarters and offices. The single-bracket light is illustrated in Fig. 291. All brackets are finished in dark bronze and are buffed before being bronzed.

This fixture is secured to a brass base with a cast boss in the side into which the conduit screws. There are two smaller bosses which may be tapped for the conduit of the switch wires.

FIG. 292.—Deck Fixture.

The double-bracket light is similar to the single type, but has two arms set about 90 degrees apart. Fluted shades are used with these fixtures.

The **bulkhead fixture, deck fixture** and **drop light** are all similar in construction, and are alike with the exception of their bases. A **deck fixture** is shown in Fig. 292.

In general it consists of a metal flanged conical base, fitted with screw-thread, on which screws against a washer a clear glass globe. This globe encloses the lamp which fits into a socket secured to the *base,* and around the globe is fixed a metal guard. All metal parts are finished with a dark bronze.

The base for the deck fixture has a boss tapped for the conduit and two vertical lugs by which it is secured to the deck.

This fixture is secured overhead under the deck, and in such places as passages, lower decks, under gratings in fire-room and engine-rooms, and in general where there is good head room.

The **drop light** has a conical base, tapped at its apex for the con-

duit. This fixture replaces the old steam-tight globe-fixture, and finds particular use for lighting fire-rooms from overhead, steam and gauge glasses, etc.

The **bulkhead fixture** replaces the old form of bulkhead fixture used with molding. Its base is similar to that of the drop light in having a central boss tapped for the conduit, but in addition it has two side lugs cast in one with the base by which it is screwed to the bulkhead.

FIG. 293.—Bunker Fixture.

It is used entirely for side lighting, and in places for overhead lighting where the drop light would require too much head room. It is used on the berth deck, for standing lights, for lighting upper decks and under bridges, and in the engine and fire-rooms. It is also installed in places where formerly was used the ceiling fixture No. 2 which is now not a standard fixture.

Bunker Fixture.—As the name implies this style of fixture is used for lighting coal bunkers. It is shown in Fig. 293. In general it consists of a cylindrical casting forming a box in which the lamp is secured, the top of the casting having a boss tapped for the conduit. The back of the casting is covered by a plate with stiffen-

ing rings, in the center of which is a hole ordinarily covered by a screw cap by which the condition of the lamp may be seen.

The front of the casting is covered with a plate of glass 1-inch thick, over which a follower ring is bolted to hold the glass in place, and which is provided with four vertical guard ribs to protect the

FIG. 294.—Ceiling Fixture, No. 1.

glass from the coal. The fixture is put in place from the outside of the bunker and is secured by $\frac{7}{8}$-inch bolts.

The **overhead bunker fixture** is somewhat similar to the ordinary bunker fixture, but is fitted to be secured overhead in a bunker and not through a bulkhead. It lights the bunker more efficiently but has the disadvantage of requiring the glass face to be removed before a lamp can be replaced.

Ceiling Fixture No. 1.—Fig. 294 shows a fixture of this type that was standard for a number of years. In the present standard, the open fancy work on the base is replaced by a brass casting with an interior boss, which is tapped for the conduit, and two extra bosses on the sides which may be tapped for conduit switch wires. The lamp screws in a standard socket secured to the base and is surrounded by a globe, frosted on the inside.

FIG. 295.—Ceiling Fixture, Commercial.

This fixture is used extensively in cabins and officers' mess-rooms where there is plenty of head room.

Ceiling Fixture No. 3 is somewhat similar to No. 1, with the exception that the lamp is mounted horizontally, and the globe is flatter and of clear glass. The interior of the base is painted white. It is used in open spaces for overhead lighting.

Ceiling Fixture, Commercial.—This type is shown in Fig. 295. In addition to the details shown it has a cast-brass base fitted with the bosses which are taped for conduit and conduit switch wires.

All ceiling fixtures are bronzed, but the bases may be painted to correspond to the woodwork.

Lantern Fixtures.

These are movable fixtures and secured to convenient receptacles by flexible conductors. They include:

Battle lantern,	**Desk light,**
Deck lantern,	**Magazine lantern,**
Cargo reflector,	**Portables, water-tight and non-water-tight.**

FIG. 296.—Battle Lantern.

Battle Lantern.—This is a hand lantern used in night action around guns, ammunition hoists, passages, etc. A type that was the standard for some years is shown in Fig. 296. It consists essentially of a cap supporting the lamp socket and which also forms the support for a cylindrical glass globe surrounding the lamp. Around the globe is fitted a wire guard and inside of which is a metal shield. One-half of this shield is fixed and the other half may be turned so as to completely shut off all light or it may be turned so that light will be thrown over half a circumference.

The present standard differs somewhat in construction, although the general features remain the same. The cap is made so that the outlet for the conductor leads in horizontally instead of vertically, and all parts, including the top and bottom pieces, handle and guard, are heavier to withstand more severe usage. It is also fitted with a hinged door on the bottom to shield the light in that direction.

The **deck lantern** is in all respects similar to the battle lantern but is not fitted with the metal guard. It is used where open lights are required on the upper decks or bridges.

Cargo Reflector.—This is shown in Fig. 297. It consists of a dome-shaped brass reflector, covered by a guard of wire mesh. The inside of the reflector is painted white. In the reflector are mounted four keyless sockets, holding four lamps. These sockets

FIG. 297.—Cargo Reflector.

are all wired in parallel and their ends soldered to the flexible conductor which leads into the top through a stuffing gland. The figure shows curved arms holding the sockets, but in the present standard the arms are done away with and the sockets are mounted

directly on the base, and are inclined about 45 degrees to the vertical.

This lantern finds extensive use as gangway lights, and for lighting coal barges or lighters where special amount of light is required.

Desk Light.—The fixture that was standard for some years is shown in Fig. 298. The present standard is very similar except

FIG. 298.—Desk Light.

that the stand is somewhat lower, and the curved support is carried up on each side of the socket and lamp and the light is not fitted to be removed. The light can be swung in its supports and clamped in any position. It is wired with double conductor, silk, and is used in officers' quarters and offices.

Magazine Lantern.—This is shown in Fig. 299 and is used for lighting magazines and shell-rooms. It is placed in a permanent box built in the ship, which is provided with openings covered by glass through which the light filters. It is composed of a rectangu-

FIG. 299.—Magazine Lantern.

lar brass box, bronzed, about 18″ × 8″, provided with circular openings in each of its four sides. Two lamps are wired in each lantern, the conductors entering the top through stuffing glands. Two sliver-plated reflectors are furnished with each lantern and they may be hung as desired to reflect the light in the required direction.

Portables.—These are of two types, known as ***water-tight*** and *non-water-tight.* The water-tight type is illustrated in Fig. 300. It is similar in construction to the general steam-tight globe fixtures of the bulkhead and deck type, but is provided with a handle for ease in manipulation, and a hook by which it may be hung up. It is wired through the handle through a stuffing gland, and the latest type is fitted with a phosphor bronze spring, about 4 inches long, surrounding the conductor. This ends in a brass casting which is fitted with a second stuffing gland. This spring protects the insulation of the wire and prevents abrasion by obviating any sharp turns of the conductor where it enters the handle.

FIG. 300.—Portable, Water Tight.

This portable finds use in engine and fire-rooms, coal bunkers, double bottoms, etc., and in places where water or moisture is apt to be found, or where hard usage may be expected.

The **non-water-tight type** is similar to the water-tight type, but is generally smaller and lighter in construction, and is not fitted with a water-tight globe. It is fitted with a ring at the top instead of a hook and the protecting spring for the insulation is left off.

Special Fixtures and Lanterns.

Special fixtures and lanterns are those used each for some specific purpose other than general illumination and including the following:

Binnacle light,
Diving lantern,
Blinker signal light,
Masthead lantern,
Night signal lantern,
Peak lights,
Range light,
Side lights,
Signal lanterns,
Stay light,
Telegraph fixture,
Top lantern,
Towing lantern,
Truck light,
Turret-hood fixture.

The **binnacle light** is used for illuminating the compass card in the binnacle. It consists of a cylindrical casing carrying a socket and lamp, and is provided with a handle by which it is lifted into or out of the opening in the center and top of the binnacle cover. It is wired through a stuffing gland on one side, the conductor leading to a receptacle usually secured on the base of the binnacle. The light from the lamp shines directly down on the center of the card.

FIG. 301.—Diving Lamp.

The **diving lantern** is used under water when required by a diver. It is furnished with double conductors, and each wire of the conductor is connected to a 25-ampere receptacle plug. The lamp and conductor is illustrated in Fig. 301. A 25-ampere switch and receptacle is provided on each bow and quarter, and in long ships, extra outlets are provided.

FIG. 302.—Masthead Lantern.

The fixture consists of a cylindrical glass globe held by metal rods between two metal caps with water-tight joints. The metal cap contains the lamp socket which is wired through a metal rod and made water-tight by a stuffing tube. This metal rod acts as a handle to manipulate the light. For a short distance beyond the stuffing gland, the conductor is wrapped with iron wire to prevent the insulation from breaking near the stuffing gland. There is a

screw connection through the outer cap to allow any moisture to be dried out. The fixture requires a conductor of a special make.

The **blinker signal light** is a form of hand lantern used for wig-wag signalling and fitted with a sliding screen by which the light is cut off at will.

FIG. 303.—Side Light Lantern.

The **masthead lantern** and **side-light lanterns** are constructed to meet the requirements of the Rules of the Road. The present standards are very slightly different from those shown in Figs. 302 and 303, principally in the method of securing them in place.

The lenses used are clear Fresnel lenses of cut glass, each lens forming a quadrant. For the masthead light two of these quad-

rants are used, making exactly 180 degrees, while for the side lights, a single quadrant lens is used in each. The lenses are each built up in five sections, the central one being a plano convex lens, the outer sections on each side are circular prisms.

FIG. 304.—Night Signal Lantern.

The lenses for these lanterns are clear glass, but for the side-light lantern, colored screens, either red or green, are fitted just inside the lenses, to provide for the starboard and port lights. The lanterns are wired through stuffing glands—in a casting at the top of the lantern, and are fitted to take two 32-candle-power lamps, though only one is ordinarily used. The lamps may be renewed through a hinged door in the back of the lantern.

For **range lights**, the regular masthead lantern is used in connection with a second one properly placed.

For **towing lights**, a second masthead lantern is used with the regularly fitted one.

For **top lights** for flagships, a lantern exactly similar to the masthead lantern is used.

The **night signal lantern** is one of four used with the regular night-signalling installation. It is illustrated in Fig. 304. It consists of two composition castings, one at each end, containing the stuffing glands for the conductors, and a top and a bottom piece into which the castings are secured, held together by side rods. Between the two end pieces are secured two 6-inch lenses with a diaphragm between them. The upper lens is red and the lower one is white.

The **signal lantern** is illustrated in Fig. 305. The lens is in one piece, with the plano convex lens as the middle section, and prisms for the outer sections. The lens is protected by a metal guard. It

is wired through a stuffing gland in a casting in the top piece for one lamp. The lenses are furnished in three colors, white (plain), red and green. The body of all the lenses is clear glass, the colored ones being obtained by flashing the colored glass on the interior of the clear lenses.

FIG. 305.—Signal Lantern.

FIG. 306.—Truck Light.

For **peak lights, stay lights** and **stern lights,** signal lanterns are used.

The **truck light** is illustrated in Fig. 306. The lantern itself is very similar to that used for night signalling, and has the same size and style of lenses, the upper one red and the lower one white. It is supported on a heavy brass casting which fits on the mast truck. It is wired for a 32-candle-power lamp in each lens.

The **telegraph fixture** is used to illuminate the dials of engine-room telegraphs. It is a 5-candle-power lamp mounted in a cylindrical box, with the lamp socket on one end, the other end being covered with a thin sheet of mica, through which the light shines. This is mounted on a rectangular brass plate which fits in guides on the back of the telegraph.

The **turret-hood fixture** is used to illuminate the drum of the telescopic sights for the turret guns. It consists of a metal casting as a base through which a 5-candle-power lamp is wired. Attached to the casting is a cylindrical casing surrounding the lamp, and the end of the casing is closed by a door. The light is thrown through the end of the casing into the sight hole, or it can be thrown on the telescopic drum by means of a sliding screen in the casing around the lamp.

CHAPTER XXIX.

MEASURING AND TESTING.

There are many laboratory methods for measuring electrical quantities and testing electrical machines, but on shipboard measurements are limited by the instruments furnished; these only being sufficient in a most general way for measuring the three electrical quantities of resistance, difference of potential and current.

The instruments ordinarily furnished to ships for electrical measurements are voltmeters, ammeters, testing sets and magnetos. In addition, on some ships may be found ohmmeters, whose principle and use will also be described.

Instruments.

Every electrical effect has a cause, and the effects produced are made the basis of the construction of electrical instruments. The effects generally taken advantage of are those falling under the head of static, heating, chemical or magnetic.

Of these effects, the last, that of magnetic, or electromagnetic, is the governing principle of the instruments furnished for use on shipboard. Instruments based on static, heating or chemical effects are used as standards to a greater or less degree and their principles will be briefly touched on.

Electrostatic Effect.—If there is a difference of electrostatic potential existing between two conductors, they tend to attract one another. If one is freely suspended while the other is immovable, the suspended one in approaching the other may be made to carry a pointer which will indicate the difference of potential. Voltmeters made on this principle are for certain ranges the most accurate, as they absorb no current, and there is no fall of potential due to the instrument itself.

Electrostatic voltmeters are made for measuring high potential difference and they are not usually suitable for measuring small voltages. Electrostatic voltmeters may be used to measure current by the fall of potential through a known resistance.

Heating Effect.—The fall of potential in a conductor due to its own resistance represents a loss of energy of electric current which reappears as heat, and which raises the temperature of the conductor. The amount of heat developed may be measured, and from this the current producing the heat may be measured.

The heat produced in a conductor causes expansion of the conductor in reference to other conductors through which the current is not flowing. This expansion may be measured and the temperature thus found, and therefore the current measured which produced it. In the Cardew voltmeter, the conductor consists of a wire of high resistance, three or four yards in length. The current that flows through this conductor is proportional to the E. M. F. at the terminals, and this current, owing to the heat produced, causes the conductor to lengthen. As the conductor expands, it sets in motion a train of wheels moving a pointer which indicates the difference of potential.

Electrochemical Effect.—When a current passes through a liquid (not an elementary substance), the liquid is decomposed, part going to that conductor where the current enters the liquid, and part where the current leaves the liquid. If the electrodes and the electrolyte are prepared according to some standard specifications, the same current in the same time will always liberate the same amount of matter. This matter can be measured and therefore the current determined.

This effect is very accurate and is used in this country as a standard for measuring currents (see under Ampere). In its ordinary form it cannot be used as a voltmeter, nor directly as an ammeter, unless the current remains constant for the whole time.

Magnetic Effect.—Several classes of instruments are made depending upon magnetic or electromagnetic effect. Some depend on the mutual attraction or repulsion of conductors carrying current due to the magnetic fields set up around them; others depend upon the reaction between a magnetic field due to some outside source and the magnetic field set up around a conductor carrying a current lying in that field, and still others depend upon the attraction between a conductor carrying a current and the field induced by it in some soft-iron core.

Siemen's Dynamometer.

An example of the class of instruments based on magnetic effects is the well-known Siemen's electrodynamometer, which is of interest on account of its being used as a standard, and on account of its being adaptable for either a voltmeter or an ammeter, or even indeed as a wattmeter. This dynamometer consists of two coils at right angles to each other, one being stationary while the other is free to revolve. The movable coil hangs from a thread secured to a spiral spring, which in its normal condition allows the coil to remain at rest perpendicular to the stationary coil. Current is sent through the two coils and the magnetic fields set up around the conductors tend to move the two coils so as to make their planes parallel. This tendency causes the movable coil to rotate against the tension of the spiral spring, and it comes to rest in a position determined by the relative strengths of the fields and that of the spring. The amount of twist given the spring in order to bring the movable coil back to its zero position is a measure of the current in the coils. The spring is twisted by means of a milled head which carries a pointer travelling over a scale which indicates the current.

If both coils are made of a large number of turns of fine wire, it can be used as a voltmeter by connecting a high resistance in series with it. It still measures the current, but this is proportional to the E. M. F. at the terminals and the force is a measure of the E. M. F.

This form of instrument could not be used on board ship, for it must be carefully leveled, and it is not direct reading, so it requires time and very careful handling, and is of not much use if the current fluctuates. It is of special value, though, for calibrating other instruments, and its permanence and reliability depends only on the spring, which experience has shown is practically unchangeable.

The voltmeters and ammeters furnished for use on shipboard come under the second class given under the heading, magnetic effect, but before they are described in detail, the general use and method of connecting up voltmeters and ammeters will be considered.

The Use of Voltmeters and Ammeters.

An ammeter, as its name implies, measures current, while a voltmeter measures voltage or difference or fall of potential. As constructed, most voltmeters are simply special forms of ammeters, though, in some cases, the opposite might be said.

An ammeter measures directly the strength of the current flowing through its coils, and in order that the current flowing in a circuit may not be altered by the introduction of the instrument which measures it, it is evident that the ammeter should have as little resistance as possible.

A voltmeter measures the difference of potential between two points, and it is clear that only so much of the current flowing as is necessary for the proper sensitiveness of the instrument should be diverted through the voltmeter. The voltmeter thus should have a very high resistance both for the sake of economy and accuracy. If a high resistance is connected in series with a sensitive ammeter that will measure small currents, then the current passing would be proportional to the voltage at the terminals and the instrument could be made to indicate volts.

The current flowing through an ammeter is proportional to the difference of potential at the terminals of the instrument, and from this it might appear that the difference of potential between two points might be measured by simply joining an ammeter between the two points, recording the number of amperes flowing and from the resistance of the ammeter infer the difference of potential between the points. But if such a low resistance as that of an ammeter be connected between the two points, the total current between those points would be materially changed and the very act of connecting the ammeter would alter the difference of potential required.

For instance, if an ammeter was connected to the terminals of a battery with no other circuit, it would not indicate the E. M. F. of the battery, but what could be obtained would be the fall of potential through the instrument. If the battery had a separate circuit, and it was desired to measure the fall of potential through that circuit, it is evident an ammeter would not be available for doing it by connecting it across the terminals of the battery. The

act of connecting the ammeter would reduce the current in the external circuit, and its resistance remaining unchanged, the difference of potential would be considerably lowered. What is wanted is the difference of potential before the instrument is introduced and what might be obtained is the difference of potential after the instrument is connected. The less current, then, that is absorbed by the instrument measuring difference of potential, the more accurate it is, and it is seen that as the ammeter has more and more resistance it develops into a voltmeter.

Further reasons for the peculiar construction of voltmeters and ammeters and the objects to be attained by them may be illustrated by a simple example.

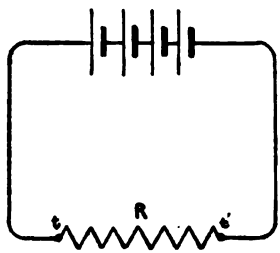


FIG. 307.

In Fig. 307 is represented a typical battery circuit, consisting of a few cells, leading wires and a resistance R joined between the terminals t and t'. If the E. M. F. of the battery is constant, there will be a constant current flowing in all parts of this circuit, the same through the battery, through the connecting wires and through R; this current depending on the E. M. F. of the battery and the resistances of the several parts. Suppose the E. M. F. of the battery and all the resistances are accurately known, then the current flowing in any portion of the circuit will be known, and the potential may be calculated for any two selected points. These results can be obtained absolutely without the use of instruments.

Let

$E = 12$, the E. M. F. of the battery;
$r = 2$ ohms, internal resistance of the battery;
$r' = 1$ ohm, resistance of leading wires;
$R = 3$ ohms, resistance between t and t';

then

C, the current flowing in any portion of the circuit, by Ohm's law $= \frac{12}{1+2+3} = 2$ amperes.

By the same law, also, the difference of potential between t and t' is $2 \times 3 = 6$ volts.

Now suppose it is wished to measure these values by instruments, the question becomes, where should they be placed in circuit or how should they be connected in order that the values already known to be correct should not be materially changed. It has already been shown that to measure a current, the current must pass through the instrument, and in order that the existing current may not be changed, the ammeter must necessarily have a very low resistance and be directly connected in series with the circuit. If the resistance is not low but still connected in series, the current value would be materially changed. If the resistance is low, but not connected in series, but as a shunt between two points, the external resistance will be reduced, thus increasing the battery current.

To measure the difference of potential between two points, the instrument must be joined as a shunt to those points, and in order that the current between them may not be greatly changed, the resistance of the voltmeter must be very great.

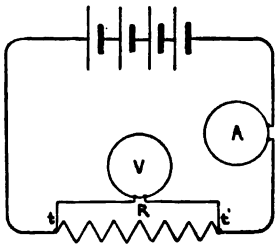


FIG. 308.

The connection of the instruments for measuring the battery current, and the difference of potential between t and t' is shown in Fig. 308.

A represents the ammeter and V the voltmeter, A connected for measuring the total battery current, and V for measuring the difference of potential between t and t'. Suppose A had a resistance of .01 ohm and V a resistance of 15,000 ohms. If V had been inserted in A's place to measure the current, the value of C would be

$$C = \frac{12}{1 + 2 + 3 + 15{,}000} = .00079 \text{ amperes.}$$

If A had been used to measure the difference of potential between t and t', C would be

$$C = \frac{12}{1 + 2 + \frac{3 \times .01}{3 + .01}} = 3.98 \text{ amperes,}$$

and the difference of potential between t and t' would be $3.98 \times (.0099 =$ joint resistance between t and $t') = .0394$ volts.

If A were put in V's place and V in A's, C would be

$$C = \frac{12}{1 + 2 + \frac{3 \times .01}{3 + .01} + 15{,}000} = .00079 \text{ amperes}$$

and the difference of potential between t and t' would be

$$.00079 \times (.0099 = \text{joint resistance}) = .0000078,$$

figures which do not bear any resemblance to the real values, and which show the effect of connecting up the instruments wrong.

If they are connected as in the figure, C would be

$$C = \frac{12}{1 + 2 + \frac{3 \times 15{,}000}{3 + 15{,}000} + .01} = 1.9963$$

and the difference of potential between t and t'

$$1.9963 \times (2.9994 = \text{joint resistance}) = 5.9877,$$

results which differ slightly from the values known to be correct.

With this arrangement the fall of potential around the circuit would be

Through the battery	$2 \times 1.9963 =$	3.9926	volts.
" " wires	$1 \times 1.9963 =$	1.9963	"
" wire t, t'	$3 \times 1.9963 =$	5.9889	"
" A	$.01 \times 1.9963 =$	.0199	"
or Total fall	$=$	11.9977	"

Care in Using and Connecting Voltmeters and Ammeters.—It has been shown by figures what the result would be by using a voltmeter for an ammeter or vice versa, but they do not tell the whole story. There ought to be no difficulty in distinguishing one from the other, for they are always marked. The reading of the scale will always be a guide, as they are marked either volts or amperes.

If an ammeter were used for a voltmeter on a high potential circuit, on account of its low resistance and the high potential a very large current would be apt to flow, damaging not only the instrument but other parts of the circuit. If a voltmeter was used as an ammeter, very little current would flow, on account of the high resistance, unless the E. M. F. was very high, in which case the delicate coils of the voltmeter might be burnt out.

Ordinarily it does not injure voltmeters or ammeters to connect them up wrong as far as polarity goes, the pointer simply indicating in the wrong direction. Too much current sent suddenly through an instrument may throw the pointer violently against its upper stop, rendering it liable to be bent. More current than is designed for may cause the coils to heat to a dangerous degree, burning or destroying the insulation of the conductors.

In making connections with a voltmeter or ammeter, it is better to make the connections on the instruments first, and to the circuit last, and still better to have a switch in the circuit, so all connections may be made without danger of injuring the terminals by the arc which might otherwise be formed.

Instruments should be used with care and judgment at all times. The best ones are made with great care with small pivots and jewel bearings, and rough handling is apt to dull the points or crack the jewels. Rough handling is also liable to weaken the permanent magnet in instruments like those of the Weston type which will cause incorrect readings.

Instruments should not be placed close to a running generator or motor, on account of the danger of having the magnetic fields distorted by the stronger fields, nor should instruments with permanent magnets be placed close to one another, not within 2 to 3 feet.

Weston Voltmeters.

The general form invariably used in the service on shipboard is that of the Weston type, being a development of the early d'Arsonval galvanometers. Two forms are usually supplied, one the station type for use on permanent switchboards, and the other a portable instrument for measurements about generators, motors, or measurements for resistance or fall of potential in different parts of a circuit. They are constructed on the same principle, already quoted under the second class of instruments given under the heading *magnetic effect.*

The permanent magnetic field is produced by a permanent steel magnet of peculiar form, half circular, half horse-shoe (see Fig. 310); the outside form of the face of the portable instrument

being in general the shape of the magnet. The form of the pole pieces is also peculiar and is such that the deflecting coil moves in a constantly uniform field, and this is necessary in order to have the deflections follow the proportional law. Between the poles of the magnet is pivoted on very sharp points resting on jeweled bearings, a very fine light rectangular coil of wire, as shown in Fig. 309. The motion of this coil is restrained by two fine spiral springs, each something like the hair spring of a watch, one at the top and one at the bottom, through which the current is led into and out of the instrument through the pivoted coil.

The index that registers the reading on the face is a long thin aluminum pointer and is secured to the top of the coil, moving with the coil as it is deflected. When no current is flowing, the action of the springs keeps the coil in its zero position, the pointer then registering zero in the scale.

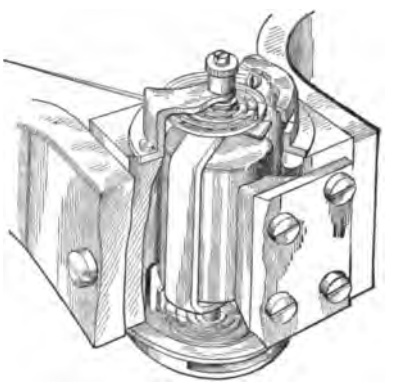


FIG. 309.—Coil and Poles of Weston Instruments.

Within the movable coil is a central cylindrical core of soft iron, this tending to strengthen the magnetic field of the permanent magnet, or rather tending to reduce the resistance of the permanent magnetic circuit. The movable coil is wound on a light copper frame, which in addition to serving as a support for the coil acts as a magnetic brake, moving as it does in an intense magnetic field and having currents induced in it opposing its motion. This makes the instrument practically "dead beat." As soon as current flows, the pointer at once takes a position to indicate the voltage and there is no "hunting" or fluctuating of the pointer.

The movable coil has a resistance of about 60 ohms and a full deflection is produced when a difference of potential of about .6 volt is applied to the coil. When measuring higher voltages than this it is necessary to insert resistances in series with the coil,

the added resistance being proportional to the maximum difference of potential to be measured. The inserted resistance must be calculated for a resistance of $\frac{60}{.6} = 100$ ohms for each scale division. To measure 100 volts would require a resistance of $\frac{60}{.6} \times 100 = 10{,}000$ ohms. This resistance is usually a coil of platinoid or manganin wire placed inside the instrument case, and as this alloy has a very low temperature coefficient, the temperature error is inappreciable and the instrument can be left continuously in circuit; the loss of power owing to the high resistance being very small.

When this voltmeter is connected to the two points of different potential, there is a temporary magnetic field set up around the movable coil, and the coil experiences a pull on one side and a push on the other tending to make it rotate, and it takes a position dependent on the resultant of the forces due to the two magnetic fields and the tension of the springs. The same current always produces the same field and the same deflection, so by proper calibration or comparison with other standards, the proper number of volts may be marked off on the scale.

As the coil moves practically in a uniform field, the subdivisions on the scale are very nearly equal.

The portable voltmeters are usually calibrated for and marked with two scales, one for high reading, and the other for low reading. The low-reading scale is made available and effective by placing properly wound resistance coils in series with the movable coil, this arrangement necessitating a third terminal on the instrument.

Weston Ammeters.

The ammeters furnished for ships' use are generally of the Weston type (see Fig. 310), and their governing principle and construction is exactly similar to that of the Weston voltmeter, the scale being marked to register amperes in place of volts. In some of the earlier forms it was usual to lead the whole current to be measured to and through the ammeter, in the inside of which was a resistance slightly greater than that of the leading wires, and the current that flowed through the ammeter coils was taken as

a shunt from the ends of this resistance. Only a portion of the main current flowed through the instrument coils, which acted in all respects exactly as a voltmeter measuring the difference of potential between the points to which it was connected.

FIG. 310.—Weston Portable Ammeter.

Ampere Shunt.

In order to obviate the necessity of leading the heavy wires to the instrument on the panel board, a later practice is to insert the resistance that was formerly placed in the instrument directly in the leads in some convenient place on the switchboard. Such a resistance is called the **ampere shunt,** and it consists of a resistance slightly greater in value than the main conductors in which it is inserted. A general form of this resistance is shown in Fig. 311.

Two copper terminals, *a, a,* are soldered to the ends of the main conductor *b, b.* Between these copper terminals are strips of metal alloy *c,* soldered in place to the terminals; the resistance being in strips to better allow for ventilation. The leads to the ammeter terminals *d, d,* are brought to the copper terminals and clamped at *e, e.*

On account of the slight increase in resistance of the metal strips over the rest of the conductor, a small proportional part of the

current is shunted through the ammeter, which thus practically measures the difference of potential between the ends of the resistance, but this, being proportional to the main current flowing, by proper calibration measures the whole current.

It is very necessary that the shunt should have a practically constant resistance as it may carry constantly varying currents and this is effected by using an alloy of low temperature coefficient, such as platinoid or manganin.

It must be remembered that the ammeter is calibrated with a certain resistance in the leading wires from the terminals of the resistance to the instrument, and the resistance of these wires must

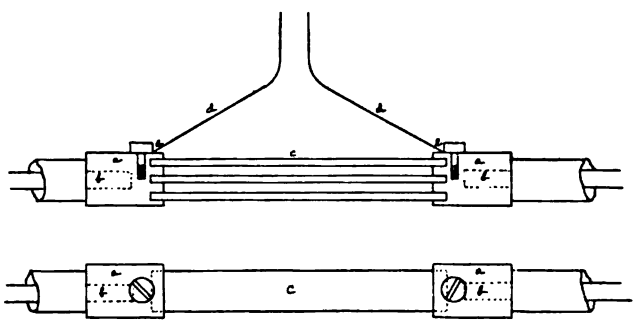


FIG. 311.—Ampere Shunt.

not in any way be changed by splicing or cutting, for the main resistance remaining constant, it is evident that the resistance of the leading wires must also remain constant if the instrument is to correctly record.

There must be perfect electrical connection between the shunt and the main conductor and between the shunt and the ammeter leads. Any resistance due to a bad contact in the former case would cause the ammeter to read too high and in the latter case too low.

The coil of the instrument is the same for all ranges and the full deflection of the needle is obtained when the difference of potential at the terminals is .06 volt. The resistance of the shunt is such that this difference of potential, about .06 volt, exists when the

shunt is carrying the maximum current and the resistance of the shunt is varied by changing the number of strips of alloy in it, their lengths remaining the same.

The Testing Set.

The testing set for measuring and comparing resistances ordinarily consists of a battery of a few cells, a galvanometer, and a combination of resistance coils of known value. The principle of all resistance testing sets is that of the Wheatstone bridge.

Before explaining the principle of the Wheatstone bridge it will be first necessary to explain the action of the galvanometer, as this instrument has been mentioned in several preceding tests, and will find constant reference in the future.

The Galvanometer.—This is an instrument for indicating and comparing currents, not to measure them, except in an indirect way. One of the most delicate instruments for showing the effect of an electric current is an ordinary magnetic compass needle. It will be remembered that the definition of the ampere was based on the effect a current of electricity produced on a magnetic pole. It will be well here to repeat the definition as finally determined on. If a conductor one unit in length (one centimetre) be bent into an arc of a circle one unit in radius (one centimetre) and a unit magnetic pole be placed at the center, then the current through such a conductor will be one unit of current if it acts on the unit magnetic pole with a force of one dyne. The effect of the current is inversely proportional to the square of the distance, r the radius, from the magnetic pole. Evidently there could be no closed circuit in such a conductor, and to make one complete turn around the pole, there would have to be a conductor in length equal to $2\pi r$. The force then in dynes which a current C would exert on a unit pole due to one complete turn would be expressed by the equation $\frac{2\pi rC}{r^2} = f$, and if the coil consisted of n complete turns, would be $\frac{2\pi nC}{r} = f$.

If such a coil surrounds a magnetic needle, each unit of strength of the needle will be acted on by a force of f dynes. The needle

is held in the magnetic meridian by the horizontal force of the earth's magnetism, this force designated by H acting on each unit of strength of the magnet. If the needle is acted upon simultaneously by these two forces it will take a position at an angle δ from the meridian that will represent the resultant of the direction of the two forces. If the coil is in the meridian, the force due to the current acts at right angles to it, and the force due to the earth acts in the meridian. Fig. 312 represents the forces acting on the needle, NS being the meridian, δ the angle of deflection, H the horizontal force of the earth tending to hold the needle in the meridian and f the force due to the current flowing in a coil in the meridian over the needle. It is evident, then, that

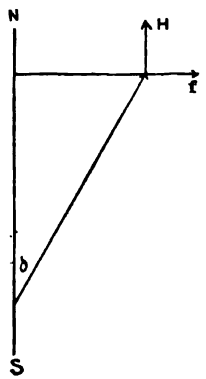


FIG. 312. Forces Acting on Needle in Tangent Galvanometer.

$$f = H \tan \delta,$$

or

$$\frac{2\pi n C}{r} = H \tan \delta.$$

These quantities all being known, it follows that C in CGS units $= \frac{r}{2\pi n} H \tan \delta$, or C is proportional to tan δ. This is the principle of the tangent galvanometer.

The Wheatstone Bridge.

The Theoretical Bridge.—The bridge (Fig. 313) consists of four arms 1-2, 2-3, 3-4 and 4-1, in three of which are variable coils of known resistance, and in the fourth, the unknown resistance X is placed. A battery B of a few cells is connected to 1 and 3, and a galvanometer G is connected to 2 and 4.

Let A, B, C and X represent the four resistances and C_a, C_b, C_c and C_x the currents in those resistances at any time.

A and B usually contain coils of resistance varying by multiples of 10, as 1, 10 and 100, and 10, 100 and 1000, and they are called the *balance* arms. The arm C contains numerous coils of resistance of such values that any whole integer may be made, and this is called the *rheostat* arm.

The current from the battery divides at 1, flows through A and C, B and X to 3 and thence back to the battery. When there is a difference of potential between 2 and 4, current will also flow in that branch, either towards 2 or towards 4, depending on the relative resistances of A and B. If current does flow through the galvanometer, it will be shown by the needle being deflected, but if there is no difference of potential between 2 and 4, no current will flow in that branch and the needle will remain at rest. When this happens a *balance* is said to be established between the four arms, and as this condition always exists in making a measurement, it is

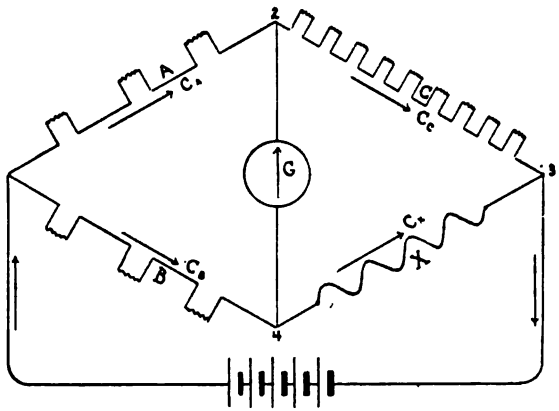


FIG. 313.—Connections of Theoretical Wheatstone Bridge.

called a *null* method. There are keys in the battery circuit and in the galvanometer circuit, so current only flows when making a test.

When current is flowing, there is a certain absolute potential at 1 and a lower potential at 3 in order that current should flow in that direction; and there is also a certain potential at 2 and a certain potential at 4. In order that there may be no *difference of potential* between 2 and 4, the fall of potential from 1 to 2 must equal the fall in potential from 1 to 4, although the currents and resistances in these branches may be different. Similarly the fall in potential from 2 to 3 must be the same as from 4 to 3. In other words, by Ohm's law

$$C_aA = C_bB \text{ and } C_cC = C_xX.$$

When there is no difference of potential between 2 and 4 the current in A is the same as in C; and in B the same as in X, or

$$C_a = C_c \text{ and } C_b = C_x.$$

Therefore

$$C_a A = C_b B \text{ and } C_a C = C_b X$$

and dividing one by the other

$$\frac{A}{C} = \frac{B}{X} \text{ or } X = \frac{BC}{A}$$

from whence A, B and C being known, X is readily calculated.

If the resistances in the balance arms A and B are equal when a balance is obtained, then the unknown resistance X is equal to the resistance found in C. If B is greater than A, the resistance in C must be multiplied by the number of times B is greater than A, and similarly if smaller than A, divided by the number of times it is smaller.

Resistance Coils.—The resistance coils are usually made of German silver wire as that is effected very little in its resistance by a change of temperature. In order to prevent the effects of self-induction due to the current and of magneto electric induction due to magnets or soft iron in the neighborhood of the coils, it is necessary that the current be doubled back on itself. The wire should be either wound on the bight as in Fig. 314, or, if there are to be many turns, the first layer should be wound right handed and the next left handed and so on, each layer being secured so as not to unwind when the next layer is wound. Then again the bobbin on which the wire is wound may be divided into halves, the upper half being wound right handed and the lower left handed.

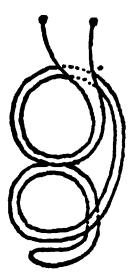


FIG. 314. Winding of Resistance Coils.

After the coils are wound they are dipped into melted paraffin, so on cooling every portion is covered, being protected mechanically and electrically.

The rheostat arm of the bridge may be used as a separate resistance, and if so used, care must be taken that too great current is not sent through coils, as they are delicate and liable to be burnt

out. The same precaution is necessary in using the galvanometer as a separate instrument, as the coils of that instrument cannot stand too heavy a current.

Silver Chloride Cell.—As has been stated this form of cell is ordinarily used in testing sets, and in order to use the set intelligently a short description of it is given. The positive electrode is a zinc rod and the negative electrode consists of a silver rod surrounded by silver chloride melted into a cylinder upon the rod. The electrolyte is sal ammoniac, but in the dry cell, as used with testing sets, the water is replaced by some gelatinous substance which differs in its composition according to the maker, it generally being a paste containing zinc oxide, zinc chloride, sal ammoniac, lime and water.

When the cell generates current the chlorine in the ammonium chloride (sal ammoniac) is displaced by the zinc and the ammonium set free displaces the chlorine in the silver chloride, leaving metallic silver deposited on the silver electrode. There will be no free gas given off unless the cell is worked too hard. This cell gives under ordinary conditions about 1.1 volts.

Galvanometer.—The form of galvanometer used with most testing sets consists of many turns of fine silk-covered wire wound on a single bobbin. The needle is pivoted and lies exactly in the center of the coil and is entirely covered by it. The needle carries a pointer at right angles to it and passes over a scale on which divisions are marked. The needle is provided with a lever for lifting it clear of its pivot when not in use, and is controlled by a separate magnet to enable it to be used in any position, the pointer showing zero on the scale when no current is flowing.

These galvanometers are made to be very sensitive, a current of one-twentieth of an ampere giving a deflection of 25 degrees. This is effected by the great length of wire used on the bobbin, the nearness of the wire to the needle and the delicate pivoting of the needle.

Service Testing Set.

One form of Wheatstone bridge furnished to ships is that made by Queen & Co., called the Queen-Acme Portable Testing Set.

The bridge, battery and galvanometer are all placed in a compact box of seasoned mahogany fitted with lock and key.

The upper face of the set is shown in Fig. 315, the full lines and circles showing the connections, binding posts, keys and terminals on the outside of the box and the dotted and broken lines the connections under the face which is of hard rubber.

The Coils.—The coils are wound of platinoid wire carefully seasoned to prevent gradual changing of the resistance with time. The wire has a low temperature coefficient and the endeavor is to have corresponding coefficients for all the coils. The rheostat coils are adjusted to an accuracy of $\frac{1}{8}$ of one per cent and the bridge coils

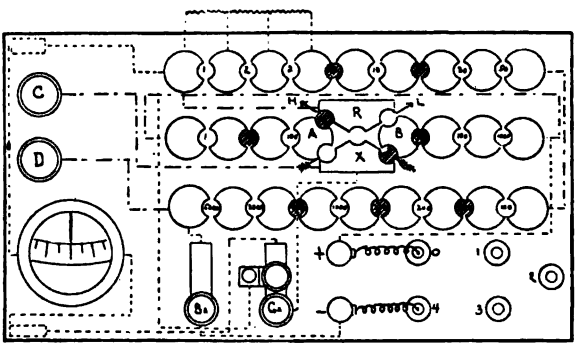


FIG. 315.—Queen-Acme Testing Set.

to an accuracy of $\frac{1}{10}$ of one per cent. The rheostat coils are sixteen in number, their combined resistance being 11,110 ohms. In each bridge arm there are three coils of 1, 10, 100 ohms and 10, 100, 1000 ohms respectively. The commutator admits of a ratio of 1 to 1000 on either bridge arm, and the theoretical range is from .001 to 11,110,000 ohms, though for resistances above 1,000,000 ohms additional battery power is required.

The Galvanometer.—This of the d'Arsonval type. The current from the battery flows in a conductor wound around an iron core on which the needle is pivoted, and this coil and core revolves between the poles of a permanent magnet which produces an intense permanent magnetic field. When current flows around the coil another magnetic field is set up, and the coil carrying the needle

takes a position due to the resultant forces of the permanent and the temporary fields.

The Battery.—This consists of four special dry cells, one or more of which may be used as desired. They maintain a steady E. M. F. and are good until exhausted. The cells have a very low resistance and will last for months with care even though the set may have daily use.

The Keys.—There are two single contact keys. The left-hand key is a single contact key in the battery circuit. The right-hand one is in the galvanometer circuit and is a short-circuit key. When depressed it closes the galvanometer circuit and when released it short circuits the galvanometer, bringing it immediately to rest.

Connections and Circuits.—The connection and circuits are readily understood by referring to Fig. 315. The top row of blocks is connected to the bottom row by a heavy copper bar joining the right-hand blocks. These two rows together constitute the rheostat. Any resistance from 1 to 11,110 ohms may be obtained in this rheostat by removing the proper plugs. The lower left-hand block of the rheostat is connected to the lower line post *D*. The upper line post *C* is connected to block *X*. This block *X* has no other permanent connection excepting that it is joined to one end of the galvanometer key. The block *R* is connected to the upper left-hand block of the rheostat and otherwise has no connection excepting by plugs. The end blocks of the middle row are connected by a heavy copper bar. Each half of this row constitutes a bridge arm, designated *A* and *B* respectively. Starting from the lower line post *D*, the circuit is continuous from there through the rheostat and then through first one bridge arm and then the other back to the other line post *C*.

The function of the commutator is to transpose the two bridge arms *A* and *B* so that they are passed through in reverse order. All of the above connections are in circuit with the resistance being measured and are made sufficiently heavy to add no appreciable resistance to the circuit.

The two battery terminals + and — are connected, one directly to the common junction of the two bridge arms, the other through the battery key to the rheostat.

The two galvanometer terminals are connected, one directly to the block *R*, while the other connects through the galvanometer key to the block *X*. The blocks *A*, *B*, *R* and *X* are joined by plugs as shown by the shaded circles between the blocks.

The Commutator.—This consists of the blocks *A*, *B*, *R* and *X* and two plugs. When these two plugs are in the position shown in the figure, the bridge arm *A* is connected to the rheostat and the bridge arm *B* to the line. In this position the following relation holds

$$\frac{A}{B} = \frac{R}{X}$$

and the bridge is in a position for measuring high resistances, indicated by the arrow marked *H*.

If the plugs have the opposite position, the bridge arms are reversed, the one that was connected to the rheostat now being connected to the line, and the one to the line being joined to the rheostat. In this position, the following relation holds

$$\frac{A}{B} = \frac{X}{R}$$

and the bridge is in a position for measuring low resistances, indicated by the arrow marked *L*.

Uses of the Set.—This testing set may be used to measure *resistances, either high or low, insulation resistance, to compare E. M. F. of batteries, to check a voltmeter, to measure battery resistances, to check an ammeter* and to make what is known as the *Varley Loop Test.* These will be described in Chapter XXX.

Magneto.

This is an instrument used in testing electrical circuits and in a limited degree for measuring resistances. It can be used to detect an open circuit, to detect a ground or to locate a fault in an open circuit, and within limits to measure resistance.

In its most common form, it consists of two parts, a small dynamo or generator and a bell. The connections are shown in Fig. 316.

The field of the generator is furnished by two or more permanent steel magnets. Between the poles is rotated a small closed

armature, usually a simple rectangular coil wound on an iron core. There is a small crank on the outside of the case containing the generator to which is attached a toothed wheel which engages a smaller wheel connected directly on the armature shaft, so one revolution of the crank gives a great many to the armature. Connected in series with the armature is the bell circuit, and when connected for testing an outside circuit, that circuit is also in series with the armature and bell circuit. Current from the armature is led around an electromagnet, between the legs of which and on the end opposite the yoke, is pivoted an iron armature. This armature has secured to it at right angles an arm terminating in a striker for the bell. This striker projects through the case, and has motion between two bells, striking them alternately as it vibrates.

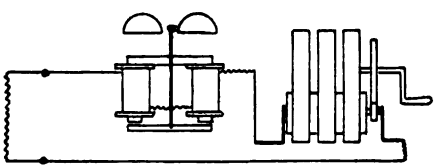


FIG. 316.—Magneto.

When the armature is revolved and the armature turned in the field of the permanent magnets, alternating currents are induced in the armature circuit and this being in series with the electromagnet causes alternating currents which cause an alternating change of polarity, causing the armature to be attracted first to one leg and then the other. This causes the striker to vibrate and a ringing of the bell is the result. This can only happen, however, when the armature circuit is complete through some outside circuit.

The E. M. F. produced in the armature depends to a great extent on the speed with which it is turned, but a good magneto should develop from 50 to 100 volts. For certain purposes, as will be illustrated later, it is necessary to know the maximum resistances that current can be forced through, and these data are usually stamped on them, varying from 3000 to 30,000 ohms.

Ohmmeter.

This instrument as its name signifies is one for measuring resistance, the value of the measured quantity being read directly in ohms from the scale of the instrument. In testing for faults or testing the goodness of the insulation used in an electric light installation, it is necessary that an E. M. F. at least as great as that under which the plant is to work, should be used. Such a high E. M. F. would be too great for use with the ordinary Wheatstone bridge testing set, so the ohmmeter is designed to be used with a small magneto giving the desired E. M. F., when the resistance can be read directly from the instrument. This instrument is of particular value in measuring insulation resistance, affording the most ready and rapid means of measuring it, its practical application being shown later.

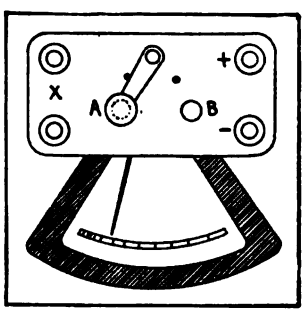


FIG. 317.—Ohmmeter.

Fig. 317 shows the general outside appearance of an ordinary ohmmeter. The two right-hand terminals are for the leading wires from the source of supply (generally a small magneto machine). They are marked + and —. The two left-hand terminals are for the leading wires to the unknown resistance to be measured. There are two contacts in the middle marked *A* and *B*, corresponding to the two scales on the face. If the switch is on *A*, the outer scale is to be used, and if on *B*, the inner scale.

Fig. 318 shows the interior construction, being a half section through the coils viewed from underneath. There are three coils, the two outer ones, *a*, *a*, being placed with their planes parallel and the coils connected in series; the third, *b*, being placed between them with its plane and magnetic axis at right angles to those of *a*, *a*. There is a small steel needle pivoted in the center of the coil *b* with its magnetic axis lying in the common axis of *a*, *a*. To this needle is attached the pointer and the coil *b* is so cut away as to allow a wide range for the travel of the pointer. Underneath the pivoted needle is a small weak bar magnet to counteract the earth's magnetism, so the needle only acts under the influence of the coils when current flows through them.

Any current flowing through *a, a,* tends to keep the needle in its zero position with its length in the common axis of *a, a.* In this position the needle is parallel to the plane of *b* and any current through *b* tends to deflect it, and the needle will take a position depending on the relative strength of the current in the coils.

The coils *a, a,* of high resistance are connected only to the source of E. M. F., but the coil *b* which is connected to the same source of E. M. F. is also connected in series to the high resistance to be measured. The current through the deflecting coil *b* is inversely proportional to the resistance and directly proportional to the E. M. F., while the current through the magnetizing coils *a, a,* is directly proportional to the same E. M. F. Any variation of the E. M. F. affects equally both the magnetizing and deflecting currents, so the deflection of the needle is simply inversely proportional to the resistance to be measured, the resistance of *b* being small.

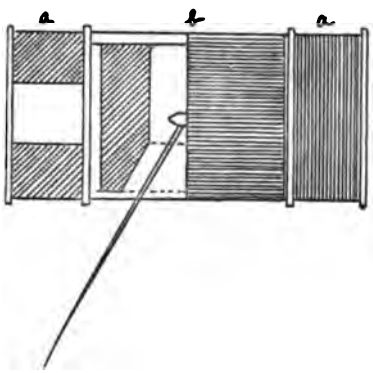


FIG. 318.—Coils of Ohmmeter.

If the resistance to be measured is infinite no current flows through *b* and there is no deflection of the needle. As soon as the resistance is at all lowered a certain small current flows producing a small deflection, and by simple calibration the scale can be marked to indicate directly in ohms the value of the unknown resistance.

The Evershed Testing Set.

The ohmmeter described in the preceding section is known as the Evershed ohmmeter, but a later form of this instrument is now made, known as the Evershed Testing Set. This instrument is made by Queen & Co., and the description and use of this instrument has been furnished by the makers.

The electrical principle involved is the same as in the case of the ohmmeter, but the arrangement of the coils is slightly differ-

ent. This is shown in Fig. 319. The leads from the magneto are secured to the terminals marked *A* (+), *B* (—), and the unknown resistance to terminals *C* and *D*, one of which is marked "Earth" and the other "Line." For testing insulation the conductor under test is connected to the earth terminal, and the other terminal is grounded.

Inside the terminals *A* and *B*, the current divides, part flowing through the coil *P*, called the pressure coil, through a constant resistance *R*, and part through the unknown resistance and through

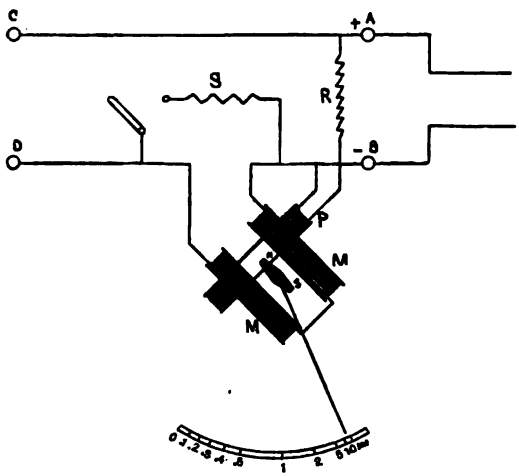


FIG. 319.—Connections of Evershed Testing Set.

the coils *MM* in series, these coils being known as the current coils. The action of the pressure coil is to keep the axis of the needle *NS* perpendicular to its own coil and that of the current coils to deflect the needle. This needle carries the pointer travelling over a graduated scale from points marked 0 to infinity.

When there is no leakage on the line, there is no current through *MM* and consequently the needle remains at rest, with the pointer indicating infinity, showing an infinite resistance on the line. When the line resistance is so low as to be negligible, the current flowing through the current coils depends on the voltage and the

resistance of the coils, and the needle will be deflected to a position in which the turning moments of the two coils *P* and *MM* are balanced. This point on the scale is marked 0 and for any given resistance in the line the pointer will come to rest at a point between 0 and infinity. The position of the pointer will not be changed by altering the voltage of the magneto, for the currents in the coils will be increased or decreased together, so their ratio remains unchanged.

The scale is marked in tenths and units of megohms, thus indicating directly the resistance measured.

Magneto.—In the latest pattern of this testing set, the magneto is built after the fashion of a modern continuous-current generator. It has a tunnel-wound armature with a finely laminated core built from stampings of best iron of "transformer" quality, a special form of commutator with elastic roller brushes and roller bearings for the armature axle. The armature is driven by double gearing by a winch handle so hinged that it may be turned into a recess in the box when not in use. A flexible double conductor connects the magneto to the ohmmeter.

Needle.—The ohmmeter has a very finely pivoted astatic needle system, magnetized by the magneto current. The needle system is automatically lifted off the jewel bearing and clamped by the action of shutting the lid of the box. The current coils *MM* are wound with an enormous number of turns of the finest wire so as to secure the maximum sensibility. A one-ninth shunt *S* is provided so as to reduce the sensibility ten times when low insulation resistances are being tested.

Instructions for Use.—Adjust the ohmmeter until the bubble is in the center of the spirit level.

Place the generator not less than 18 inches away from the ohmmeter and couple its terminals to the marked terminals on the ohmmeter.

Couple the mains to be tested to the *line* and *earth* terminals of the ohmmeter. Turn the generator handle steadily in either direction at any speed above 60 revolutions per minute and the ohmmeter index will point to the resistance under test.

CHAPTER XXX.

MEASUREMENTS.

The measurements to be given are only those that can be made with the instruments described in the preceding chapter, viz.: the voltmeter, ammeter, testing set, magneto and ohmmeter. In addition to the above, a few standard resistances may be necessary, but they can usually be found on board ship, as, for instance, the rheostat arm of the testing set when small currents are used, or the "ampere shunt" resistance used with the ammeter when large currents are used.

To Measure Current.

Current is measured by connecting an ammeter directly in the circuit through which the current is passing.

To Measure Current without Opening the Circuit.—This can be done where there is a convenient switch in the line, for the ammeter may be connected around the switch, and the switch then opened, when the full current will pass through the ammeter.

To Measure Current by Resistance and Voltmeter.

By Ohm's law the fall of potential through a conductor equals the product of its resistance and the current then flowing. By knowing the resistance and measuring the difference of potential between its ends, the current is at once obtained. Fig. 320 shows how the connection should be made.

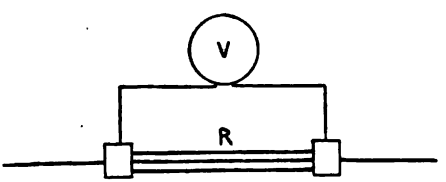


FIG. 320.—Connections for Measuring Current with Resistance and Voltmeter.

R is the standard resistance and V the voltmeter, which in this case should be a low-reading one.

To Measure E. M. F.

E. M. F. is measured by connecting a voltmeter to the two points between which the difference of potential is required.

To Measure Resistances.

High resistance may be measured by a voltmeter, by the testing set or by an ohmmeter.

Low resistance may be measured by an ammeter and voltmeter, or by a voltmeter and standard resistance.

To Measure Resistance with Voltmeter.—To do this requires a voltmeter of known resistance and a source of constant potential, as a running generator. The difference of potential across the mains of the generator is first measured and then the resistance to be measured is connected in series with the voltmeter, and the fall of potential through these two is measured across the mains whose difference of potential is constant. This is represented in Fig. 321.

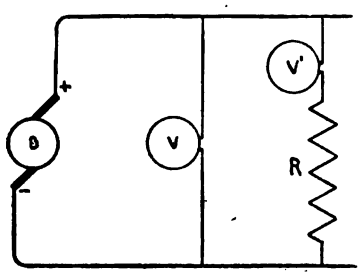


FIG. 321.—Connections for Measuring Resistance with Voltmeter.

Suppose V is the reading of the voltmeter when connected directly across the mains and V' the reading when it is connected up with R, the unknown resistance in series with it. Let X be the resistance of the voltmeter and C the current through V' and R, then by Ohm's law $V = C\ (X + R)$ and $V - V' = CR$.

Subtracting one from the other,

$$V' = CX \text{ or } C = \frac{V'}{X},$$

also

$$C = \frac{V - V'}{R}.$$

$$\therefore \qquad R = \frac{(V - V') \times X}{V'},$$

all of which quantities are known.

This method is available for high resistances and is particularly adapted for measuring insulation resistance as described farther on.

To Measure Resistance of a Voltmeter.—This is just the converse of the above, requiring a source of constant potential and a high resistance. The connections and readings are made as before, when the resistance of the voltmeter would be equal to the other resistance multiplied by the second reading and divided by the difference of the readings.

The resistance of most voltmeters is marked on the box or case, but the above would be available in case it was unknown.

With a Weston 150-volt range voltmeter satisfactory resistances can be measured from 100 to 2500 ohms, the most accurate being for resistances about equal to that of the voltmeter. With the low-reading voltmeter, from 0 to 5 volts, a range from 3 to 85,000 ohms may be measured.

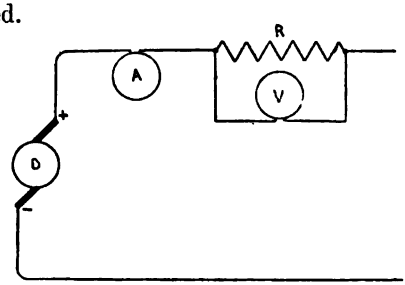


FIG. 322.—Connections for Measuring Resistance with Voltmeter and Ammeter.

To Measure Resistance with an Ammeter and a Voltmeter.—To do this it is only necessary to connect up the resistance in series with the ammeter and connect a voltmeter at the terminals of the resistance. Then, by Ohm's law, the resistance is at once calculated.

From above $R = \frac{V}{A}$ (Fig. 322).

Precautions when Measuring Resistance with Ammeter and Voltmeter.—See that the instruments are far enough apart so that neither will be effected by the other, and use no more current than is suitable for the resistance. See that all connections are good, and especially those of the voltmeter. It is better to connect the ammeter outside the voltmeter, for the error will be less if the ammeter measures the slight current through the voltmeter than if it were connected so that the voltmeter recorded in addition the fall of potential through the ammeter.

To Measure Resistance with a Voltmeter and Standard Resistance.—The circuit whose resistance is to be measured is connected in series with the standard resistance and a steady current sent through both. The voltmeter is connected around the standard resistance and then around the unknown resistance. The current being the same through both resistances, the differences of potential are directly proportional to the resistances. A typical connection is shown in Fig. 323 for measuring the resistance of an armature.

A few cells are connected up in series with the standard resistance and the armature whose resistance is to be determined. A voltmeter is connected to the terminals of the resistance and when

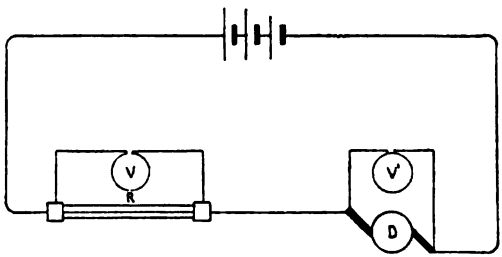


FIG. 323.—Connections for Measuring Resistance with Voltmeter and Standard Resistance.

current is established through the circuit, the fall of potential through the resistance is noted. When the same current is flowing, the voltmeter is connected to the brushes of the armature or to two opposite segments of the commutator, and the fall of potential noted. Calling R and D the resistances and V and V' the readings of the voltmeter, then the current C through R and D is, by Ohm's law,

$$C = \frac{V}{R} = \frac{V'}{D} \text{ or } D = \frac{V'R}{V},$$

whence D is readily calculated.

In this measurement, the standard resistance should be capable of carrying considerable current without heating, and the "ampere shunt" resistance can be used to advantage. The current should be steady, and the resistance of the voltmeter high, and the voltmeter itself low reading.

Standard Resistances.—If no resistances are available, they can readily be made on board ship. Knowing the resistance required, and its diameter and specific resistance, its length can be determined as given under the subject *Resistance*. Its calculated resistance should be checked by actual measurement by some of the methods given.

Calibration of Instruments.

Calibration is the process of determining the value of the current or voltage required to move the indicator to any or all parts of the scale. This may be done when making a new scale or in checking an instrument that has been in use. For example, suppose that an instrument has a resistance of 10,000 ohms, and that .001 ampere causes the pointer to move an inch from its zero point. By Ohm's law $E = C \times R$ or $E = .001 \times 10{,}000 = 10$ volts, so that point on the scale one inch from the starting point might be marked either 10 volts or .001 (one milliampere). When this instrument is connected between two points and current flows through it so that the pointer takes this position, it is then known that a current of .001 ampere is flowing through it, or that the difference of potential between the points is 10 volts. In a similar way the value of any other point on the scale may be determined.

All voltmeters and ammeters should be calibrated from time to time by comparison with some standard instruments. To be accurate they should be compared with absolute standards, but as they are not available on shipboard, it is usual to compare all instruments with some standard, which in turn might be calibrated on shore by reference to absolute standards.

Calibration of Ammeters.—To compare an ammeter with a standard they are connected in series and the same current is sent through both, the deflection of the needle of the standard being noted and that of the other being compared with it. If the instrument has not changed the readings should be the same.

The instruments should be placed far enough apart so that the magnetic field of one does not affect the other, and the instruments should be in the same relative position, that is, both level if the standard is correct in that position, or both vertical, as the case may be.

If a standard ammeter is not at hand, a standard resistance and a millivoltmeter may be used, and the current flowing through the resistance calculated, and this should be the value indicated on the ammeter under test. The connections are shown in Fig. 324.

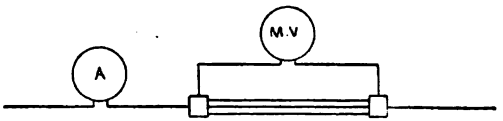


FIG. 324.—Connections for Calibrating Ammeters.

The instruments should be compared with increasing and then decreasing currents to check against errors of hysteresis and to see how far the instrument is affected by friction.

Calibration of Voltmeters.—Voltmeters are compared with a standard voltmeter by connecting all in multiple, so that all are subjected to the same voltage. The voltage is then changed to different values and the reading of the voltmeters is compared with the standard.

To Obtain Different Voltages.—In order that voltmeters can be compared throughout the range of the instrument, some means must be adopted of varying the voltages. A good method of doing this is to connect across the mains of a constant potential circuit, such as the lighting mains on ship, a piece of wire that will allow a small current to pass. A conductor of German silver wire is especially adapted for this, as its resistance per unit of length is uniform, so the fall of potential will be uniform.

By connecting the voltmeters in multiple along this wire any difference of potential may be obtained, and comparisons with the standard made. It is well to have one common terminal secured to one of the mains, and another common terminal may be moved along the wire. The connections are made in Fig. 325.

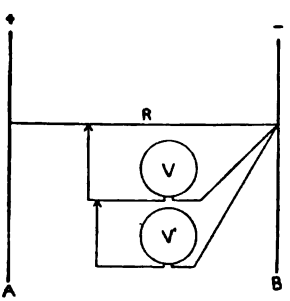


FIG. 325.—Connections for Calibrating Voltmeters.

A and *B* represent the mains and *R* the German silver resistance, *V* the standard voltmeter and *V'* the one under comparison.

To Connect Voltmeters to Increase their Range.—It may happen that a voltage is desired to be measured that is beyond the range of the voltmeter at hand. The range of the voltmeter may be doubled by placing it in series with an equal resistance. If the voltmeter reading to 150 volts has a resistance of 15,000 ohms, it will read to 300 volts when it is connected in series with an added resistance of 15,000 ohms or another voltmeter of the same resistance. This results from the fact that if the resistance of the circuit is doubled, twice as much pressure is required to send the same current through. If these two voltmeters are connected between two points whose difference of potential is 300 volts, each instrument will register 150 volts, the fall of potential through each being 150 volts. The total fall of potential will be the sum of the fall of potential through each instrument.

To Connect Voltmeters to Decrease their Range.—Most portable voltmeters are provided with two resistances, by means of which two scale readings are available, one for high and one for low differences of potential, and separate terminals are provided for putting these resistances in the circuit. It frequently happens that a high-range voltmeter is the only means at hand for measuring voltages, and a small difference of potential may be wished to be measured. Weston voltmeters are marked in single volts, but frequently they are not accurate within the first few divisions on the scale of the high-reading instruments. In this case it is better to connect the points between which the E. M. F. is required in series with the voltmeter and connect them both across high potential mains.

Suppose it was required to measure the E. M. F. of a battery with a voltmeter whose range was 150 volts. Connect the battery in series with the voltmeter and connect them both across the lighting mains, say an 80-volt circuit. If the voltmeter showed 78.5 or 81.5 volts, it would indicate that the battery had added or subtracted 1.5 volts, depending on how its poles were connected, and therefore the E. M. F. of the battery must be 1.5 volts.

Uses of the Testing Set.

The uses of the Queen-Acme testing set are taken from the circular issued by the makers of this instrument, Queen & Co., and which is furnished with the instrument.

To Measure Resistance.—Resistances are measured with the Queen-Acme as follows:

Connect the terminals of the resistance to be measured to the line posts *C* and *D*, and place the battery connectors on the two upper tips. This throws one cell of the battery into circuit, which is sufficient until balance is roughly attained. Now unplug the 100-ohm coil in each bridge arm, and place the commutator plugs for either high or low resistances. Remove plugs from the rheostat until the aggregate resistance unplugged is, as nearly as may be guessed, equal in value to that of the unknown resistance. Then press the battery key, and, holding that down, momentarily press the galvanometer key. If the galvanometer needle swings toward +, the resistance unplugged in the rheostat is too high and should be reduced. If the deflection is toward —, the resistance is too low and should be increased. By altering the resistance in this way a value will soon be found wherein a slight change either way will reverse the deflection of the galvanometer needle. The rest of the battery may now be put in circuit by placing the right-hand battery connector on the lower left-hand tip. If the keys be again pressed, first the battery key, then the galvanometer key, a greater deflection will be obtained than before for the same variation in the rheostat, and therefore the adjustment can be made more accurately. With bridge arms of equal value this is the best result that can be obtained, but by selecting more suitable values for the two arms a considerably higher degree of accuracy may be secured. A reference to the following table will show the best values of the bridge arms to determine any desired resistance.

The following table shows the values of *A* and *B* respectively, to be chosen when measuring any resistance within the range of the set:

Below	1.5	ohms, make	A = 1, B = 1000	Plug for Low.
Between	1.5 and 11	" "	A = 1, B = 100	
"	11 " 78	" "	A = 10, B = 100	
"	78 " 1100	" "	A = 100, B = 1000	
"	1100 " 6100	" "	A = 100, B = 100	Plug for Low or High.
"	6100 " 110,000	" "	B = 1000, A = 100	Plug for High.
"	110,000 " 1,110,000	" "	B = 1000, A = 10	
"	1,110,000 " 11,110,000	" "	B = 1000, A = 1	

Placing the Plugs.—In placing the plugs in the commutator it is sufficient to remember this:

First. Excepting when the two arms are of equal value, *always* make arm *A* the *smaller.*

Second. If the resistance being measured is higher than 6100 ohms, place the commutator plugs for high; if lower than 1100 ohms, for low. In the first case, the unknown resistance is found by dividing the larger bridge arm by the smaller, and *multiplying* the total unplugged resistance in the rheostat by the quotient. In the second case, the rheostat resistance is *divided* by the quotient. The arrows on the top of the set facilitate setting the commutator plugs. If measuring high resistance, set the plugs in the direction indicated by arrow *H;* if measuring low resistance, follow direction indicated by arrow *L.*

Example.—An example will illustrate the method of using the bridge. It is desired to measure a resistance say of about 1000 ohms. Connect the resistance to posts *C* and *D,* arrange the commutator in the direction of arrow *L,* place battery connectors on upper tips, and remove the 100-ohm coil from each bridge arm. From the rheostat unplug 1000 ohms, and upon pressing the keys the galvanometer needle swings to —. Unplug 100-ohm coil, and galvanometer needle swings to +. Try 1050 ohms, moves to —. Try 1070, still —. Try 1090, moves to +. With 1080, needle reverses again, swinging to —. Try 1085, swings to —. Try 1087, it swings to +. Try 1086, swings to —. The true value is, therefore, between 1086 and 1087. To secure more accurate results, change bridge arm *B* to 1000, and remove 10,860 ohms from rheostat. This proves too little. Try 10,865, and it is found too large. It is probable that with 10,000 ohms out no change in deflection will be noted smaller than will be produced by a change of 5 ohms in rheostat. We see that 10,860 is small and 10,865 large, the true value, therefore lies between them, or say 10,863.

Very Low Resistances.—In measuring very low resistances, excellent results may be secured by interpolation. Supposing a resistance of about .01 ohm is to be measured. Make the bridge arms 1000 and 1 respectively, and arrange the commutator with the plugs in the direction of arrow *L.* Unplug 10 ohms from rheostat, and

needle swings to +. Try 5 ohms, and it reverses, swinging to —. Another trial demonstrates that the correct value lies between 7 and 8. That is .007 and .008 ohm. Now to determine the result accurately note the values of the two reverse deflections when 7 and 8 ohms, respectively, are out. In the former case the deflection is — 1.4 divisions; in the latter case, + 4.1 divisions. The 8 comes more nearly balancing; or, in other words, the true value is more nearly 8 than 7. Now divide the larger deflection by the sum of the two deflections, and annex the quotient to the smaller value removed from the rheostat. $\frac{41}{55} = .56$ or .00756 ohm for the resistance desired.

To Compare E. M. F's. of Cells.—Connect in all of the cells in the set in the usual way, taking care, however, not to reverse them by crossing the battery cords. Plug the commutator only between *B* and *R*, and remove 1000 ohms from bridge arm *B*. Arm *A* should be all plugged *in*. From the rheostat unplug say 5000 ohms. Now, connect one of the cells, whose electromotive forces are to be compared with its positive terminal, to the + battery post, and its negative terminal to the line post *C*. Upon pressing the keys the needle swings one or the other way. If towards + unplug less resistance in rheostat, and if toward — add resistance to rheostat. A value will quickly be found wherein a variation of an ohm either way reverses the deflection. Now, take this value and add to it the resistance unplugged in arm *B*. This divided by the resistance in arm *B* gives the ratio between the potentials of set battery and test cell respectively. It will be noted that the division is decimal and consists merely in pointing off as many places as there are ciphers in the resistance unplugged from arm *B*.

This operation repeated with any number of cells gives their values in terms of the battery E. M. F. in the set from which their relative values may be obtained. Or, if desired, a standard cell may be used to replace the battery in the set, in which case the first measurement gives at once the value of the E. M. F. of the test cell.

If the E. M. F. of the cell or battery being tested exceeds that of the battery in the set, it is only necessary to reverse the positions of the two batteries, when the results are secured as before.

To Check a Voltmeter.—A voltmeter may be checked up, to determine its accuracy, while in service. Disconnect the battery of the set. Connect the circuit to the battery posts of the Queen-Acme set, positive lead to + post, negative lead to — post. Before doing this, remove say 10,000 from rheostat, plug commutator only between *B* and *R*, and remove 100 ohms from arm *B*. Now, connect a standard cell or one whose E. M. F. is known with positive terminal to + battery post, and negative terminal to line post *C*. Upon pressing both keys a deflection occurs towards + if rheostat resistance is too high; towards — if too low. A few changes will produce a result wherein a slight variation in the rheostat resistance reverses the galvanometer deflection. To find the E. M. F. on the line, add 100 to the rheostat resistance and point off two. Multiply this by the E. M. F., and the result is the desired E. M. F. If the standard is exactly one volt, the total resistance out represents the E. M. F. on the circuit.

The attainable accuracy is greater than could be secured with the best voltmeter, in fact, it is an excellent method of checking the accuracy of all voltmeters.

Battery Resistance.—To measure internal resistance of a cell, first compare its open circuit potential with the potential of battery in set as previously explained. Now, shunt it with a known resistance, say 100 ohms, and again measure its terminal potential. The difference between these values, divided by the shunt resistance, gives the current flowing. To find the internal resistance, multiply the resistance of shunt by ratio between first value measured and second. This method has one important feature; it determines the internal resistance under normal conditions of use, since the shunt may be given any desired value. One is enabled to give a low value to the shunt, and make repeated balances while the cell is discharging, thereby determining the effect of polarization.

As an example of the application of the Queen-Acme to the internal resistance of a battery, take say a silver chloride testing cell and determine its resistance. Measuring its potential in terms of test battery, we find it is .212 of the latter. Shunting it with 1000 ohms, and repeating the measurement we find .179 for the terminal E. M. F. The total resistance, therefore, is to the 1000

ohms shunt as 212 is to 179 or the total resistance $= \frac{212}{179} \times 1000 = 1184$. Deducing the shunt we have 184 ohms as the internal resistance of the cell.

To Check an Ammeter.—To check an ammeter with the Queen-Acme, secure a low resistance and proceed as follows: Connect the low resistance in series with the meter and run leads from it to the Queen-Acme set; one lead from the positive side of the + battery post, the outer from the negative side to the line post *C*. Join a standard cell between the battery posts; positive to + post, negative to — post. Plug commutator between *B* and *R;* remove say 10,000 from rheostat, and 100 from arm *B*. Balance in the usual way by changing rheostat resistance. Now, the difference of potential at the terminals of the shunt has been balanced against the standard cell, and is found by the directions previously given for comparing E. M. F's. to equal shunt

$$PD = \frac{1.44 \times 100}{R + 100} = \frac{144}{R + 100}.$$

To determine the current flowing, divide this result by the shunt resistance. As the shunt resistance has usually a decimal value, it is necessary merely to point off in the last operation.

Use of the Keys.—The primary use of the keys is very evident, that in the battery circuit to prevent current from flowing all the time, thus running down the battery, and that in the galvanometer to protect that when not in use. It has been stated in making a measurement, the battery key should be first pressed, and at an interval, the galvanometer key. The nature of certain resistances may cause the potential of any two points to be widely different when the current is starting or stopping and yet they may be at the same potential when the current is steady. A current can never rise or fall to its full value instantaneously, and when the unknown resistance is such that the rise or fall takes place at a different rate, the current must be allowed to become steady by first closing the battery key, and then closing the galvanometer key.

In measuring a resistance like that of an electromagnet in which there is great self-induction, or a long line in which there is electrostatic capacity, the proper use of the keys becomes very

important. Although there may be an exact balance, yet if the galvanometer key is closed first, the needle may be violently thrown, owing to the momentarily induced current.

In measuring the resistance of an electromagnet, the galvanometer must be placed some distance from it, so it will not be influenced by the magnetic field set up around it. The effect can be tested by opening and closing the battery switch, leaving the galvanometer key opened. If there is any movement at all of the needle, it is proof that some part of the circuit is disturbing it, and this should be corrected before the measurement proceeds any farther.

Earth Test.—If it is not possible to bring both ends of the unknown resistance to the bridge, the test can still be made by connecting one end to the bridge and connecting the far end to a good "earth" connection, and also making connection to earth of one pole of the battery. The earth being at the same potential, will act as though the two were connected to a common terminal. The terminal of the bridge where the far end of the resistance and the pole of the battery would connect is also connected to earth. The measurement is now made as before.

Uses of the Magneto.

This instrument finds constant use on board ship for locating breaks or faults in circuits, for locating grounds and to a limited extent for measuring certain high resistances. It is of particular use while wiring circuits and for tracing out breaks in bell circuits, and finds use, too, to a certain extent in testing out the various windings of a generator or motor, as it quickly locates faults or grounds.

To Test for Open Circuit.—On the outside terminals, there are usually connected two short pieces of connecting wires. To test a circuit, these leading wires are secured to the ends of the circuit, and the armature is rapidly revolved. If the circuit is closed, current flows through the armature, around the electromagnet and through the outside circuit, thereby causing the bell to ring. If the circuit is broken no current flows and the bell does not ring.

It is always well to short circuit the terminals and then revolve the armature to see if all the connections in the magneto itself are intact and the circuit continuous.

To Detect a Ground.—Connect one terminal to the circuit to be tested, and the other to a good "ground" or "earth" connection through a steam pipe, or to a bulkhead or the ship's side, seeing that the paint is scraped off to get connection with the bare iron. If there is a ground on the line, current will flow through the ground back through the ground connection and the bell will ring. If there is no bad ground, the bell will not ring.

To Locate a Fault in an Open Circuit.—Suppose a break showed on one leg of an electric-light circuit. Unscrew all the lamps on that circuit and ground both ends of the conductor. Go to a point about midway of the line, and at some junction box connect one terminal of the magneto to one end of the conductor where disconnected and the other terminal to ground. Ring through. If the bell rings, that part of the circuit is complete. Connect the other end of the conductor where disconnected to the magneto and ring through. If there is no ring, the break is in that part. Connect the circuit again and go to some other point in the direction of the break and ring through again both ways. A few trials like this will soon develop and discover the break.

To Test for Breaks, Leaks or Grounds in Generator Windings.—Treat them exactly as though they were separate circuits, first seeing that all circuits are disconnected from one another and the brushes raised from the commutator. To see if there is a leak from the series winding to the shunt winding, connect one terminal of the magneto to the series winding, the other to the shunt, and ring through. To test an armature for grounds, connect one terminal to the armature through a brush and the other to ground and ring through. The connections to be made will readily suggest themselves to obtain the desired result.

To Measure Resistance by a Magneto.—Each magneto has stamped on it the number of ohms through which current can be sent and consequently the bell rung. The ordinary resistance through which the bell can be rung varies from 15,000 to 30,000 ohms. Knowing the value for a particular magneto, the loudness

of the ringing furnishes a rough idea of the resistance being rung through. When the bell rings almost as strongly as when short-circuited, it shows the resistance is very low. When it does not ring at all, it shows that the resistance is above the value for that particular magneto. If it rings feebly, it shows the resistance is very high.

To Increase the Sensitiveness of a Magneto.—Although the resistance of a circuit may be so high that the bell will not ring through it, in some cases the continuity of the circuit may be shown by putting the hands in circuit. This is done by putting one terminal of the magneto between two fingers and touching the back of the hand to the end of the circuit. Wetting the fingers and back of the hand will add to the sensation of current.

Wrong Indications of a Magneto.—As a magneto gets old, the permanent magnets are apt to lose some of their magnetism, so the voltage for the same number of revolutions grows less, and the magneto will not ring through as high a resistance as when new. The magneto may be short-circuited and the bell rung through any resistance; or some of the connections may get broken or worn out, and the bell not rung through any resistance.

A magneto may sometimes ring by simply connecting it up to a circuit in which there is great capacity, even though the circuit is open, thereby giving a wrong indication. There is more or less capacity in all parallel circuits, and a magneto will sometimes ring when connected to the ends of a long coil of double conductor, such as lamp cord, even though the resistance to continuity of circuit may be millions of ohms.

Measurements of Insulation Resistance.

Insulation resistance may be tested either for the ohmic resistance of the insulation or for the ability of the insulation to withstand the potential to which it is ordinarily subjected.

If only the ohmic resistance is required the insulation may well be tested by the Testing Set, but for the ability to stand high potential as well as ohmic resistance the ohmmeter with a small magneto is preferable.

Insulation by Direct Deflection.—Insulation resistance may be measured by the testing set by direct deflection. Connect a known high resistance, say 100,000 ohms, one terminal to the line post *C*, one terminal to the + battery post. Remove all plugs from the commutator, and have all plugs in the rheostat, as any resistance unplugged in rheostat is in circuit with galvanometer and battery. Arrange battery tips so as to connect in one cell only. Now upon pressing the keys a deflection of about 8 divisions will be obtained. This deflection is due to the current from one cell through 100,000 ohms. If we multiply the resistance by deflection we have that resistance through which one cell will produce a deflection of one scale division. This is the constant of the galvanometer.

Now, replace the known high resistance by one whose value it is desired to know, and add enough cells to produce as large a deflection as possible. Multiply the constant of the galvanometer, usually expressed in megohms, by the number of cells and divide by the number of scale divisions deflection. The result is the desired resistance expressed in megohms.

If a high resistance is not at hand, one may be readily made for temporary use by marking with a soft pencil on a strip of ground glass. Connect the glass by means of tinfoil ends to the posts of the set, and measure its resistance, adding or removing a small amount of graphite until the desired value is secured.

Method by Testing Set.—The following is the method generally used as a quarterly test required by the regulations. One leading wire is taken from one terminal of the unknown resistance of the bridge to one bus bar on the switchboard. The connections of all voltmeters, ammeters and ground detectors are broken, as well as connections from the generators, this last effected by leaving the main headboard switches open. Another leading wire leads from the other terminal of the unknown resistance to a good earth connection. All lamps in all the different parts of the ship are unscrewed from their sockets, and it is well to test each circuit for continuity by the magneto, as this will tell whether any lamps have inadvertently been left in place. Open all the switches controlling the different circuits at the switchboard. When all ready to go on with the measurement, close a switch connecting one leg of the

circuit to be tested to the bridge. As all connections are broken, the circuit can only be completed through grounds or leaks along the one leg of the circuit back to the earth connection to the bridge. Measure the resistance by the bridge or at least ascertain that it is over some fixed value, say 2 megohms, which it should be in a good circuit. Record the result. Open the switch and close another on the same bus bar, repeat the measurement and record it, and so on until measurements on all circuits have been made on the same bar, say all the + legs. In the case of searchlight circuits, see that the carbons are run apart, and in motor circuits that the circuits are disconnected at the brushes.

After finishing all the + legs, disconnect the leading wire from the + bus bar and connect it to the — bar, and repeat all the above measurements, recording the results in tabular form, numbering the circuits and distinguishing the legs of a circuit by + and —.

The result of the above measurements will give the insulation resistance of each leg of each circuit to earth, and to obtain the total resistance of each circuit to earth add the reciprocals of the resistances of each leg, and take this receptacle.

After the above series of measurements has been made, disconnect the leading wire from the earth connection and take it to the terminal of the bus bar not already connected. Now close both switches of a circuit, leaving all the others open, and all lamps being disconnected, current is only established through leaks from one leg of a circuit to the other. This is a necessary measurement as it might happen that the resistance of each leg to earth was very high, but that from one leg to the other was very low. Repeat this measurement for each circuit on the switchboard.

After this series of measurements is completed, then close all the switches and the resistance will be that of all circuits connected in parallel, which in the poorest installation should not fall under one-half megohm.

Machine Insulation Resistance.—The testing set can be used in a similar manner to test the ohmic insulation resistance of the different circuits of generators and motors. The different windings are disconnected, the brushes raised and connections to the switchboard broken. Keeping one terminal of the unknown resistance to

earth, the other may be connected to the different parts and windings, and measurements taken and recorded, as from armature to earth, series winding to earth, shunt winding to earth, etc. By making the proper connections by the leading wires from the bridge such insulation resistances can be made, as armature to series winding, or to shunt winding, or to engine shaft, or to frame, or to earth; or from shunt to series, shunt to armature, shunt to shaft, or such other combinations as will suggest themselves for examining the goodness of insulation.

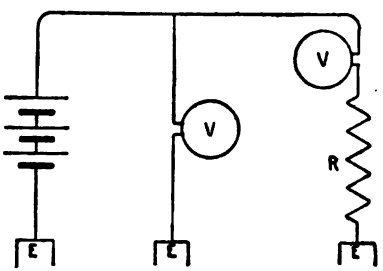


FIG. 326.—Battery Connections for Measuring Insulation Resistance.

Method by Drop of Potential Using Battery and Voltmeter.—The method of using the battery and voltmeter is shown in Fig. 326.

Let E = E. M. F. of battery,
b = resistance of battery,
X = resistance of voltmeter,
d_1 = deflection of voltmeter connected across battery terminals,
d_2 = deflection of voltmeter in series with insulation resistance,
R = insulation resistance,
C = current through battery, voltmeter and R,

then

$$C = \frac{E}{R + X + b} \text{ and } C = \frac{d_1 - d_2}{R},$$

or

$$\frac{E}{R + X + b} = \frac{d_1 - d_2}{R} \text{ and } E = d_1,$$

whence

$$R = \frac{(X + b)(d_1 - d_2)}{d_2};$$

b is so small that it may be neglected.

Method by Voltmeter.—The method described of measuring insulation resistance by means of the bridge necessitates stopping the generators, or at least cutting off the current from the switchboard, but the voltmeter uses the generator current as the source of supply. The only instrument required in making this measurement is a portable voltmeter of known resistance, and the necessary connections can be made in a few minutes time, if they are not part of the switchboard installation.

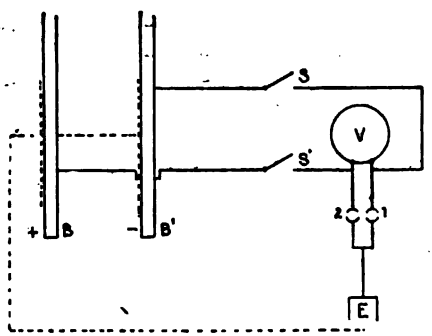


FIG. 327.—Connections for Measuring Insulation Resistance by Voltmeter.

In Fig. 327 B and B' are the bus bars connected to the generator terminals. V is the voltmeter, each terminal having a connection to earth through the plug switches 1 and 2. The bus bars are connected to their respective terminals of the voltmeter through the switches s and s'.

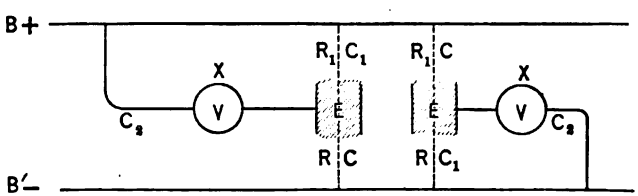


FIG. 328.—Voltmeter Connections to Ground.

The values of the insulation resistance of B and B' to earth may be deduced by a consideration of the connections shown in Fig. 328.

When the voltmeter is connected between B, the + side, and earth E, there may be leaks from B to E and from B' to E.

Let V = difference of potential between B and B',
V' = deflection shown when B is connected to earth,
V'_1 = deflection shown when B' is connected to earth,
X = resistance of voltmeter,

then

$$C_1R_1 + CR = V \text{ and } C_2X + CR = V,$$
$$C_1R_1 = C_2X = V - CR = V', \quad C_1 + C_2 = C.$$

The joint resistance of R_1 and X is

$$\frac{R_1X}{R_1 + X},$$

and

$$C\left(\frac{R_1X}{R_1 + X}\right) = V' \qquad C = \frac{V - V'}{R},$$

or

$$\frac{V - V'}{R}\left(\frac{R_1X}{R_1 + X}\right) = V' \text{ and } R = \frac{V - V'}{V'}\left(\frac{R_1X}{R_1 + X}\right). \quad (1)$$

This shows that the value of R, the insulation resistance of B' to earth, depends on the value of the insulation resistance of B to earth. If the voltmeter is connected between B' and earth and gives a deflection V'_1, a similar deduction will give R_1 in terms of R, thus

$$R_1 = \frac{V - V'_1}{V_1}\left(\frac{RX}{R + X}\right). \quad (2)$$

From equations from (1) and (2), the values of R and R_1 will be found to be

$$R = \frac{X(V - V' - V'_1)}{V'}, \quad (3)$$

and

$$R_1 = \frac{X(V - V' - V'_1)}{V'_1}. \quad (4)$$

If the + leg is not grounded, $V'_1 = 0$, and

$$R = \frac{X(V - V')}{V'}, \quad (5)$$

and if the — leg is not grounded, $V_1 = 0$, and

$$R_1 = \frac{X(V - V'_1)}{V'_1}. \quad (6)$$

Example.

A direct reading voltmeter, having 16,000 ohms resistance is connected from the + main to earth. The voltmeter shows 2.6 volts and the difference of potential between mains is 110 volts. Find the insulation resistance between the — main and earth, assuming that the insulation resistance of the + main to earth is (1) infinite; (2) the same as the — main to earth, and (3) one-tenth of the — main to earth.

If the insulation resistance of the + main is infinite, that leg is not grounded, and from equation (5)

$$R = \frac{X\,(V - V')}{V'} = 16{,}000 \times \frac{110 - 2.6}{2.6} = 660{,}900 \text{ ohms.}$$

Under condition (2) $V' = V'_1$ and from equation (3)

$$R = \frac{X\,(V - V' - V'_1)}{V'} = 16{,}000 \times \frac{110 - 5.2}{2.6} = 644{,}900 \text{ ohms.}$$

Under condition (3) $V'_1 = 10\ V'$,

and $$R = \frac{X\,(V - V' - V'_1)}{V'} = 16{,}000 \times \frac{110 - 28.6}{2.6} = 500{,}900 \text{ ohms.}$$

Suppose it is required to measure the insulation resistance of the — legs to earth. One circuit is taken at a time, the others being cut out; both section switches on the bus bars are closed. The switch s' is closed and plug switch is inserted in 1. The only current then through the voltmeter is from the + bus bar through the voltmeter, through the switch 1 to earth and from earth to earth leaks along the — leg, and thence to the — bus bar. All the — legs can be tested in this way in a few minutes, recording for each circuit the reading of the voltmeter.

To test the + legs, take one circuit, keep both section switches closed; close s, open s' and insert plug in 2. The current is then from + bus bar to leaks along the + leg to earth to the voltmeter through 2, through the voltmeter and switch s to the — bus bar. Record the reading of the voltmeter and do the same for each leg.

The bus bar voltage can be determined by opening both 1 and 2 and closing s and s'. Having this voltage and the drop due to earth leaks, we have the data necessary for calculating the insulation resistances.

Knowing X and V and assuming a value for R beyond which its actual value is not desired, V' can be calculated. If a reading shows above this calculated value, R is less than the assumed value, and vice versa.

Suppose it was not wished to know the actual resistance, provided the resistance to be measured was over 2 megohms, and the voltmeter had a resistance of 13,000 ohms, and we were using an 80-volt circuit then

$$2{,}000{,}000 = \frac{13{,}000 \times 80}{V'} - 13{,}000,$$

or

$$V' = \frac{1{,}040{,}000}{2{,}013{,}000} = \tfrac{1}{2} \text{ volt practically.}$$

If the voltmeter showed $\frac{1}{2}$ volt or less, the insulation resistance for the particular part measured would be 2 megohms or over.

This is a very rapid and easy method and the insulation of the different legs of the different circuits to ground can be tested at any time while the generator is running, and besides it has the advantage of the high potential of the running machine. The only observations are V and V' for each measurement and these can be recorded for each circuit, and the calculations can be made after the tests are finished, the whole operation only consuming a few minutes.

Method by Ohmmeter.—To measure insulation resistance by this method requires the use of an ohmmeter and a magneto. The leading wires from the magneto are connected to the proper terminals on the ohmmeter and the circuit to be tested is connected to the other set of terminals. The same preliminary operations as in the other methods are necessary. If one leg is to be tested to earth, one terminal is connected to the leg and the other terminal to earth. The armature of the magneto is rapidly revolved and current is sent through the ohmmeter and circuit, being completed through grounds or leaks. The ohmmeter measures directly the resistance of the circuit being tested, and the result is read off directly from the scale. This is by far the most rapid and convenient method of making this test, and not only is the ohmic resistance of the insulation measured, but the circuit is tested for its ability to stand the high potential developed by the magneto.

It sometimes happens that the resistance measured with a low potential differs from the same resistance measured with a high potential, due to the electrostatic attraction of the conductors under the influence of high potential.

The magneto and ohmmeter can be used to test out the different windings and insulation resistance of the various parts of generators and motors in a way similar to that described for the magneto alone, and under the heading "Machine Insulation Resistance."

Measurement of the Resistance of Generator Windings.

As an illustration of the general methods of measuring resistances by the use of instruments furnished to ships, a general description will be given of the measurement of the resistances of the different parts of a compound generator; namely, the shunt winding, the series winding and the armature. These values are usually furnished as part of the data when the generators are installed, but it may become necessary to verify them, or to make the measurements in testing for faults or breaks.

The Shunt Winding—By the Bridge.—The resistance of the shunt field is usually sufficiently large to be measured by means of the bridge, the ends of the winding being disconnected from the generator terminals and connected to the terminals of the bridge for the unknown resistance. It requires some skill in making this measurement, as when current is sent around the shunt coils or the circuit is broken at the key, the momentary self-induction reacts on the needle of the galvanometer and gives it a motion which is not its true motion due to the current flowing around it. This can be obviated to some extent by keeping the battery key pressed down some time before the galvanometer key is pressed, and releasing the latter key before the battery key. In making this measurement by the bridge, if possible the balance arms should be equal, so that the resulting reading in the rheostat arm may not have any error multiplied or divided.

By Voltmeter and Ammeter.—A more satisfactory way of measuring this resistance is by means of a voltmeter and ammeter, connecting the former to the shunt field terminals and disconnecting one end of the field windings and inserting an ammeter in series with it.

Then start the generator and let it build up to its full voltage, and the instant it has attained this voltage, read both the voltmeter and ammeter. Dividing then the number of volts by the

number of amperes will give at once the resistance of the shunt winding in ohms. It is necessary to take the readings the moment full voltage is reached, because the moment current flows around the shunt coils, heat is generated in them, thereby increasing the resistance. The first readings will give the cold resistance, or the resistance of the copper itself. It is usually necessary to know the hot resistance of the shunt winding, which is calculated by taking the readings of the voltmeter and ammeter after running for two or three hours. If the field has four shunt spools, the total resistance divided by four should give the resistance of each spool, though it is always better to check the measurement by shifting the voltmeter to the terminals of each field spool separately, leaving the ammeter in circuit as before.

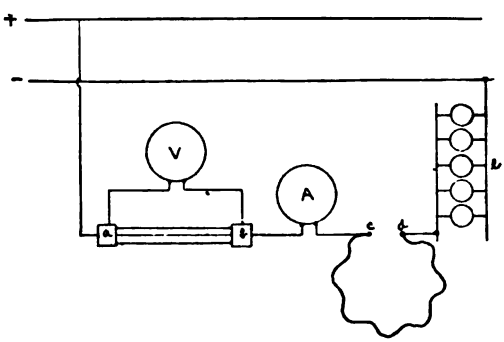


FIG. 329.—Connections for Measuring Resistance of Series Winding.

Series-Winding Resistance.—The resistances of the series windings and armatures of generators and motors are so small, usually less than .01 of an ohm, that measurement by the bridge is not satisfactory. The method generally practiced and which gives good results, is the fall of potential method. This method of measuring the resistance of an armature has been given under the heading, "To Measure a Resistance with Voltmeter and Standard Resistance," but the following method is a little more practical and with more details:

The connections for making measurement of the series winding of a generator are shown in Fig. 329. For this measurement, cur-

rent is taken from the switchboard, or some convenient mains or feeder, being energized by another running machine. The standard resistance *a, b,* is connected in series with the series winding, and in addition, a resistance *e* is inserted in series, to steady the current and to prevent short-circuiting the running machine. The standard resistance *a, b,* should have a resistance somewhat near the supposed resistance of the unknown resistance, say .01 ohm. The resistance *e* can readily be made of lamps, so arranged in series and parallel as to give almost any desired result and being heavy enough to withstand the heavy currents.

Only enough current is required from the running generator to give a good readable deflection on the voltmeter, and it is well to insert an ammeter in circuit, as shown at *A,* in order to know just what current is flowing. It is best to start with a low-testing current and gradually work up to the value decided on.

A low-reading portable voltmeter is used and is connected to the terminals *a* and *b,* and the current varied by changes in the lamp bank until a good deflection is obtained. The final reading of the voltmeter is recorded and the current being kept steady, the voltmeter is connected to the terminal of the series winding and the reading noted. With the three known quantities, the two readings of the voltmeter and the known resistance, the unknown resistance is calculated by the formula previously given,

$$R' = \frac{V'R}{V},$$

from which it is seen that the accuracy of the measurement depends on the accuracy of the known resistance.

For very low resistances a current of 10 to 100 amperes may be necessary and a voltmeter reading to thousandths of volts.

Armature Resistance.—The same method can be used to determine the resistance of an armature, by disconnecting two ends from the commutator and connecting them in series with the known resistance, or by connecting the brushes in circuit with the resistance. If the last method is used, the brushes must make good contact with the commutator, and all other connections broken, and the value obtained will depend on the number of brushes and on the manner in which they are connected.

Contact Resistances.—The fall of potential method, with a high resistance, low-reading voltmeter, may be used to determine the goodness of contacts in binding screws, or from terminal leads to the brushes, or from the brushes to the commutator. Good contacts should show very low resistances which would be indicated by low readings of the voltmeter.

CHAPTER XXXI.

FAULTS OF GENERATORS AND MOTORS.

A generator or motor considered simply as a mechanical machine is a very simple affair and the parts in which troubles may arise are few in number, the only moving or wearing parts being the commutator, brushes and bearings. To make it a complete electrical machine, to these may be added the armature core with its windings and the field pieces with the field windings.

Troubles may occur in any of these parts due either to faults within the machine itself, or to faults occurring outside the machine, in the external load that the generator or motor is supplying, the effects being conveyed to the machine and manifested there.

Every fault has its effect and the same effect may be traced to widely different faults, and a fault may produce one or more different effects. In order to definitely determine the proper relation between faults and effects, we may either tabulate the faults and trace the effects, or tabulate the effects and assign to them the faults.

The following table is self-explanatory and shows how intimately the different faults are connected, and with its help the cause of any particular fault may be traced.

FAULTS.	CAUSE.	HOW MOST READILY DETECTED.	REMEDY.
1. Too high voltage.	1. Too high speed of engine.	1. Voltmeter reads greater than standard, and lamps burn with undue brilliancy.	1. Slow the engine.
	2. Too strong magnetic field.	2. Same.	2. Introduce more resistance in shunt field.
2. Too low voltage.	1. Too low speed of engine.	1. Voltmeter shows lower than standard and lamps burn dimly.	1. Increase speed of engine.
	2. Too weak magnetic field.	2. Same.	2. Take out resistance in shunt field.
	3. Brushes not properly set.	3. Same.	3. Rock brushes back and forth till highest voltage is shown.

FAULTS.	CAUSE.	HOW MOST READILY DETECTED.	REMEDY.
3. Excessive current.	1. Too many lamps burning or motors running.	1. By too high reading of ammeter for capacity of machine.	1. Cut out necessary number of lamps or reduce motor current.
	2. In a motor, too much mechanical work being done by it.	2. By excessive sparking of motor brushes and too high reading of motor ammeter.	2. Reduce the load on the motor.
	3. In a dynamo, too much power being absorbed by motors in circuit.	3. By excessive sparking of dynamo brushes and too high reading of dynamo ammeter.	3. Reduce load on motor circuits. In this case, none of the motors may be doing too much work, but there may be too many in dynamo circuit.
	4. Short circuit; leak or ground in external circuit.	4. By excessive sparking of brushes, and heating of *whole* armature.	4. Locate and remove leaks or grounds.
	5. Short circuit in armature coil.	5. By heating of short-circuited coil more than the others.	5. Stop machine. Locate coil. If entirely burnt out, must be renewed.
	6. In a dynamo, by excessive friction in bearings of a motor or by motor armature striking pole pieces. In general any cause tending to slow motor.	6. By sparking of dynamo brushes. By sound of armature striking while running. By heating of motor bearings.	6. File away pole pieces of motor, or recenter armature. Clean and oil journals, or refit bearings.
	7. Grounds in armature. Two grounds to the core amount to a short circuit.	7. Same as 5.	7. Locate the grounds. Reinsulate the coils containing them.
4. Excessive sparking at brushes.	1. Excessive current; therefore due to any of the causes given under that head.	1. Same as given under "Excessive current."	1. Same as given under "Excessive current."
	2. Brushes improperly set.	2. By the sparking itself and heating of brushes.	2. Shift the brushes backwards or forwards till sparking is reduced to a minimum.
	3. Brushes make poor contact with commutator.	3. Same, and by sighting underneath between brushes and commutator.	3. Adjust, file or clean brushes until they rest evenly on commutator with light but even pressure.
	4. Rough, non-concentric commutator.	4. By the sparking. A rough commutator can be detected by lightly touching finger nail to it while running; an eccentric commutator by the regular rise and fall of the brushes.	4. Smooth commutator with fine file or fine sandpaper. If eccentricity is due to uneven wear of bearings, renew or reline them.
	5. "High" or "flat" bars in armature.	5. By the jumping or vibrations of the brushes.	5. Same as above, or turn down the commutator in lathe.
	6. Broken circuit in armature or commutator.	6. Commutator flashes, and nearest the break is cut and burnt. Flashing continues when armature is slowly turned.	6. Locate coil by drop of potential method. If in commutator, bridge over the break. If in armature coil, it must be renewed.
	7. Weak field magnetism, caused by broken circuit in field winding or short circuit in same; two or more grounds in windings; reversal of one or more field coils.	7. Dynamo fails to generate full E. M. F. If very weak, motor runs very slow.	7. Short circuits or grounds are easily located and remedied if external to the windings. If internal, faulty coil must be rewound or repaired if only grounded. A reversed coil will lower the voltage instead of increasing it, and it is remedied by reversing the connections.
	8. Unequal magnetism.	8. One brush sparks more than the other.	8. Only remedied by reshaping pole pieces.

FAULTS.	CAUSE.	HOW MOST READILY DETECTED.	REMEDY.
	9. Dirty commutator, causing brushes to vibrate, particularly if of carbon.	9. Flashing around commutator.	9. Clean commutator (methods given later).
	10. Poor brushes, especially if of high-resistance carbon hard blisters forming on them.	10. By ragged appearance of brushes around edges and formation of hard spots.	10. Renew brushes.
	11. Vibration, especially of brush holders, causing rapid vibration of brushes.	11. By a humming, singing sound of brushes.	11. Reduce cause of vibration or give the brushes a little greater pressure on commutator.
5. Heating of armature.	1. Excessive current through it and therefore due to any of the causes given under that head.	1. Same as given under "Excessive current."	1. Same as given under "Excessive current."
	2. Eddy currents in core.	2. Core becomes hotter than armature coils after running for a short time.	2. Only remedied by better design of core lamination.
	3. Conduction from other parts as from commutator or bearings, the heat being conveyed to armature. If from commutator, bars may be too small.	3. Other parts connected to armature, as commutator, shaft or bearings, hotter than the armature.	3. Locate source of heat by thermometer or feel by the hand, and correct it by cleaning and lubrication.
6. Heating of commutator.	1. Too great pressure of brushes, friction causing heat.	1. By feeling the commutator with the hand.	1. Reset brushes.
	2. Excessive sparking.	2. Same.	2. Discover the cause of sparking and correct it, according to the particular cause given under sparking.
	3. Excessive current.	3. Same.	3. Discover cause of excessive current and correct according to particular cause already given.
	4. Conduction from other parts.	4. Same.	4. If from bearings, lubricate or refit them.
7. Heating of field coils.	1. Excessive current in field circuit, due to short circuits or grounds.	1. Too hot to bear by the hand. If exceedingly hot, by smell of burning shellac or varnish or charring cotton.	1. Locate the particular coil in which fault lies and repair or rewind. Methods given later.
	2. Eddy currents in pole pieces, heat being conducted to the coils.	2. The pole pieces are hotter than the coils after a short run.	2. Only remedied by better design.
8. Heating of bearings.	1. Lack of lubrication.	1. By feeling with hand. Oil cups empty or feeding pipes clogged.	1. Fill oil cups; clean feeding pipes.
	2. Dirty or gritty bearings.	2. By feeling with hand.	2. Remove cap and thoroughly clean.
	3. Bearings out of line.	3. Unequal wear of bearings, and shaft will not turn freely by hand.	3. Bearings must be lined up or shells rebabbitted. If very serious, new bearings will have to be made.
	4. Rough or cut shaft.	4. Shaft will show the roughness in the bearings.	4. Turn down shaft in lathe, or if not too bad, reduce by filing.
	5. Shaft bent.	5. Unequal wear in bearings and armature will wobble. Very hard to move by hand.	5. Shafts can only be straightened by disconnecting from armature and reheating and reforging.

FAULTS.	CAUSE.	HOW MOST READILY DETECTED.	REMEDY.
9. Too low speed (referring to motors).	1. Too much load.	1. By speed indicator; heavy sparking, heating of all parts and bearings.	1. Decrease E. M. F. at terminals of motor or reduce the work to be done.
	2. Any of the causes given under "Heating of bearings" causing excessive friction.	2. Same, and same as given under "Heating of bearings."	2. Discover particular cause and remedy same as given under "Heating of bearings."
	3. Weak magnetic field and heavily loaded.	3. See cause 7, under "Excessive sparking."	3. Same as 7 under "Excessive sparking."
	4. Short circuit or grounds in armature.	4. By motor taking excessive current without load as shown by ammeter or heavy sparking and heating.	4. Same as under 5, "Excessive current."
	5. Too low voltage at terminals.	5. By motor voltmeter or speed indicator. By heavy sparking and heating.	5. By correcting line voltage.
10. Too high speed (referring to motors).	1. Too light load (in series motors).	1. By noticeable increased speed.	1. Increase load.
	2. Weak magnetism (if lightly loaded).	2. Same.	2. Same as 7 under heading "Excessive sparking."
	3. Too high voltage at terminals, due to high voltage of dynamo.	3. Same.	3. Correct line voltage by remedies 1 and 2 under "Too high voltage."
11. Dynamo fails to generate E. M. F.	1. Too weak residual magnetism, caused by a jar or reversal of current not sufficient to reverse magnetism.	1. Very little attraction by the pole pieces when tested with a piece of iron.	1. Send a current through field from a few cells or from a running dynamo.
	2. Short circuit within machine, or grounds in field windings.	2. Magnetism very weak.	2. Locate the grounds or short circuits and correct them.
	3. Reversed field coils.	3. All poles should have alternate magnetism; if a coil is reversed, it will show magnetism, but may not be of opposite polarity.	3. Make polarity opposite by reversing the connections of the coil. Each pole should be opposite to the one on each side of it.
	4. Series and shunt windings connected up opposite to each other.	4. Voltage falls as speed is increased, the external circuit being closed, showing that they are working against one another.	4. Reverse connections of either field, but not both.
	5. Brushes not properly placed.	5. Magnetism and E. M. F. increased by shifting the brushes.	5. Find central position by experiment or from drawings of connections.
	6. Open circuit due to broken wire, brushes not on commutator, switch open, connections loose, fuses burnt out.	6. If break or loose connection is in machine, magnetism will be very weak. If in external circuit, machine will show its regular magnetism and voltage at the terminals.	6. Make diligent search outside of machine. If in machine, test the circuits with magneto for continuity. Set up on all connections.
12. Motor fails to start.	1. Too much load.	1. No motion and fuse in circuit melts or circuit-breaker acts. See if motor runs all right when light.	1. If motor does not start at once, turn off current and search for cause. Reduce load on motor.
	2. Excessive friction, due to any causes given under heading "Heating of bearings."	2. Same, and motor hard to turn when not loaded, and with no current.	2. Remedies same as given under "Heating of bearings."

FAULTS.	CAUSE.	HOW MOST READILY DETECTED.	REMEDY.
	3. Short circuit of field or armature or among connections.	3. Motor refuses to revolve, though shows signs of strong magnetism. Will turn easily by hand if unloaded and with no current. If current is very great, it is indication of short circuit. If fault is in field, magnetism will be weak.	3. If connections are made wrong, consult maker's diagram and correct them. Test for continuity and short circuits as given later.
	4. Open circuits due to field switch open, fuse melted, loose or broken connections, or some fault at generator.	4. Weak magnetism shows a loose connection in field circuit; no magnetism, that field switch is open. May be heavy current in armature. If there is no armature current there will be no spark at brushes when raised.	4. Turn current from motor, and search for cause of discontinuity; examine all switches, fuses and connections, tautening all. Test for continuity in machine circuits and repair broken or burnt-out coils.
18. Flickering of lamps.	1. Uneven running of engine, probably due to governor failing to properly function.	1. By flickering of lamps or vibration of voltmeter indicator.	1. Overhaul engine, especially governor.
	2. Loose connections, either on machine, switchboard or external circuit.	2. Same.	2. Examine all connections and see that they are firm and make good contact.

CHAPTER XXXII.

TESTS FOR AND LOCATION OF FAULTS.

Under the heading *Remedy* given in the table of the preceding chapter most of the remedies given are simple and explain themselves, as for instance: Remedy No. 1, under Fault No. 1, "slow the engine," which would of course be done by throttling down the steam; No. 2, "Introduce more resistance in shunt field," which would be done by a proper manipulation of the field regulator. Some, however, are but indicated, as No. 4, under Fault No. 3, "Locate and remove leaks or grounds," and it is the purpose of this chapter to enter a little more into the detail of the simple tests and the location of the faults.

Short Circuit in External Circuit.

This would be indicated by the melting of the fuses in that circuit, or possibly by the melting of the main fuses or by the opening of the circuit breakers. After determining the circuit on which the short is, an examination along it, if accessible, may lead to its location. If not, it can be tested for by the magneto or ohmmeter, by unscrewing all the lamps and opening the circuit at different points and ringing through both ways. Working from the switchboard, try the feeder first by disconnecting at the feeder junction box. By connecting the ohmmeter to the two ends, its resistance can be roughly measured; that is, it is either very high if the short is not there, or infinitely small if it is. By opening the circuit at various points, the short can be located within limits and further observation will accurately determine it.

The short circuit indicated by the melting of the circuit fuse would show that it was either on the feeder or mains; for each branch being protected, if it occurred in a branch it would only burn out the branch fuse. Short circuits in the external circuit

do usually occur in branches and particularly in portables, but then they are easily located as the branches are short. Most of them are due to moisture in the wiring accessories, or to the insulation being torn from portable wires, or burnt by hauling over hot coals or ashes.

Grounds in External Circuit.

A ground on an external circuit would be indicated by the ground detector, either of two kinds or both being connected to the mains.

Lamp Detector.—This, with its connection, is shown in Fig. 330.

A represents a positive bus bar, and *B* a negative bus bar, from which lead circuits through the ship. 1 and 2 are two incandescent

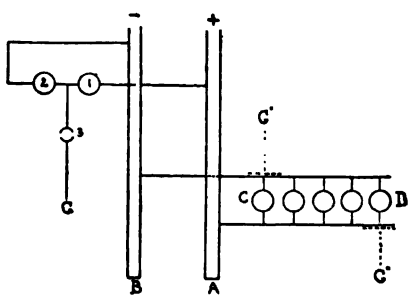


FIG. 330.—Connections of Lamp Ground Detector.

lamps connected in series across the bus bars. Between the lamps there is a connection to earth marked *G*, with a plug 3 to make the connection to earth complete. *C* and *D* are lamps on a circuit. If there are no grounds on the circuit, the lamps 1 and 2 will burn with equal brilliancy, but reduced candle-power, as with the same E. M. F. there is double the resistance, so only half the current flows through each lamp. If a ground occurs on the negative leg of the lamp circuit, the current will now flow from the + bar through 1, but will avoid the high resistance of 2, so will take a path through ground to the ground on the main as at *G'*, and thence to the — bar. The result of this is that 1 now has full current and will burn with full candle-power, while 2 will be extinguished. If it is only a slight ground, both lamps may burn but with unequal

brilliancy. If the ground was on the positive leg, the current would now avoid 1, taking the path through ground G'' to G through 2 to the — bar, and 2 would burn with increased brilliancy while 1 was lowered if not extinguished.

With several circuits closed from the bus bars and a ground appears, it becomes necessary to discover on which circuit it is, and this is done by cutting out the circuits, one at a time. On cutting out a circuit, and the ground disappears, it must have been on that circuit. On locating the circuit, keep that circuit in and cut out all the others. Then pull out the portables on that circuit one at a time, and if the ground disappears when a certain one is pulled out, the ground must have been on that particular portable, and it may then be sought and found.

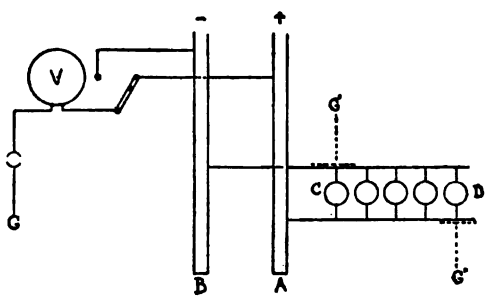


FIG. 331.—Connections of Voltmeter Ground Detector.

Grounds generally are due to moisture in the junction boxes or wiring accessories, or to the slipping of connections in lamp sockets, by which a bare wire may touch the outside shell which in turn may rest against some grounded conductor. A fruitful source of grounds is in the portable ventilating fans, the support frequently touching some exposed part of the leading wires.

Of course, grounds may occur in the mains, due to moisture rotting the insulation, and this can be tested for with the magneto, connecting one end to the main, the other to a ground and ringing through.

Voltmeter Detector.—Fig. 331 represents the typical connections for using a voltmeter to detect grounds. V is a double-reading

voltmeter with the zero in the middle of the scale, the indicator being deflected to the right or left, depending on the direction of the current through it. One terminal is connected to a contact piece fitted with a switch by which it may be connected to either bus bar of the generator, *A* or *B* and the other terminal is connected to a ground through a plug switch.

If connected as shown to the positive bar and there are no grounds on the negative side of any of the circuits, there will be no current through the voltmeter and no deflection, or the reading will be zero. If there are any grounds on the negative side, as at *G'*, current will then flow from the + bar through the voltmeter to ground *G* to *G'* and to — bar. If it is dead ground, the full difference of potential between the bars will be indicated; if only a slight ground, the fall of potential, owing to the high resistance, will be very small.

Connected to the negative bar, any grounds on the positive side of the circuit will be detected, the current then being from the positive bar through the ground, as at *G''*, through ground *G*, through voltmeter to negative bar; the indicator now deflecting in an opposite direction to that of the first case.

The method of locating the particular circuit on which the ground exists is exactly the same as with the other ground detector, and also the same procedure is necessary to further locate the ground in the circuit.

The method of calculating the ground resistance is given on page 717.

Short Circuit in Armature.

A short circuit in the armature usually attracts attention by the smell of burning varnish or shellac. When this is discovered, the armature should be stopped at once, and felt all over by the hand, the short-circuited coil being much hotter than any of the other parts. A piece of iron held near a revolving armature with a short-circuited coil will be strongly affected once a revolution, as the coil passes the iron. If a large part of the armature is short-circuited, it is not so easy to distinguish the parts by the heat, so some fall of potential method is resorted to.

One way is to pass a strong current through opposite commutator bars and measure the difference of potential between the points where contact is made with the commutator. Then connect one terminal of a portable voltmeter to one connection and the other terminal to the different bars of the commutator. If the armature is sound, there should be the same fall of potential from the leading-in point to bars each side equally distant from it. In this way the fall of potential from bar to bar may be determined, and the fall should be regular, and if between any two bars there is a smaller fall of potential than the average it shows the presence of a small resistance, or probably the short-circuited coil.

A short-circuited armature coil can only be remedied by rewinding.

Short Circuit in Field.

Usually a short circuit is confined to the windings of one spool; the effect of which will be to cause weak magnetism in the short-circuited coil, and a piece of iron held at an equal distance between poles will be more strongly attracted by the good one than by the weak.

A short-circuited coil will cause the resistance of the total field to be much reduced, and this can be detected by roughly measuring with the bridge. The fall of potential method can be used to detect the spool in which the short circuit is.

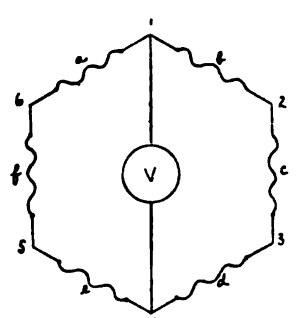


FIG. 332.—Testing for Short Circuit of Field Windings.

Suppose the coils are represented by *a, b, c, d, e* and *f,* in Fig. 332, and a source of current is connected to 1 and 4. Measure the fall of potential between 1 and 4, between 1 and 6, 1 and 5, 1 and 2, 1 and 3. The fall between 1 and 6 should be the same as between 1 and 2; between 1 and 5 the same as between 1 and 3, and consequently between 5 and 6, and 4 and 5 the same as between 2 and 3, and 3 and 4. If this symmetry does not exist between any two coils, then that coil must be the short-circuited one. The short-circuited coil should be cooler than the others.

Grounds in Armature.

A single ground in an armature is not a source of trouble, but two or more, especially in the same coil, become a short circuit with its evil effects. The particular coil in which grounds to the core exist may be determined by connecting all the commutator bars together by wrapping them with a conductor and passing a current through this wire, taking the other leading wire to the iron core. Current then flows through the armature coils through the grounds to the iron core, thus magnetizing the coil in the vicinity of the grounds, and these points can be detected by a small compass needle moved around the armature.

Grounds in Field.

The effect of grounds in the field is to short circuit a coil, and they can be detected and located in the same manner as a short-circuited coil.

Fracture in Armature.

This can usually be detected by violent flashing on the commutator, the commutator bar nearest the break being burnt or cut. A bad case of high or low bars may produce this same flashing, but if produced by this cause, it will disappear when the armature is slowly revolved, which will not be the case if caused by a fracture.

A fracture can be detected by a magneto which will not ring through a broken circuit, and can only be found by fall of potential, the same as in detecting a short circuit in armature. A voltmeter, one terminal connected to the leading-in wire, will not indicate when connected to adjoining bars until it has passed the break, for up to that time there has been no complete circuit, but when one terminal is on one side of the break and the other terminal on the other, the circuit is complete, and the fall is indicated. The fractured coil must lie between the commutator bars where one does not indicate and the adjoining one does.

In case of armature-coil fracture no particular coil will be heated more than another; if anything, the fractured coil being cooler than the others, as the current does not flow through it.

Fracture in Field Winding.

If there is a complete fracture of both the series and shunt windings in a compound generator, it will probably refuse to excite. The test for fracture can be made with the magneto, and the coil containing the fracture detected by fall of potential.

Suppose in Fig. 333 *a, b, c, d, e* and *f* represented the field coils in a six-pole machine, and that they were connected with a source of current at the terminals marked + and —. If there was a break in a coil, say in *e,* a voltmeter connected to 7 and 6 would not indicate; nor would it if connected to 7 and 5, but if connected to 7 and 4, it would indicate, the circuit now being complete, showing the voltmeter had bridged over the break in coil *e.* If there was also a break in *d,* connection between 7 and 4 would show no current, but would between 7 and 3. Connection between 3 and 4 would show no indication if there was a break in both *d* and *e,* but would if it was only in *d* alone. If breaks were in both *d* and *e* connection between 3 and 5 would show current, and in this way it can be determined absolutely in which coils breaks occur.

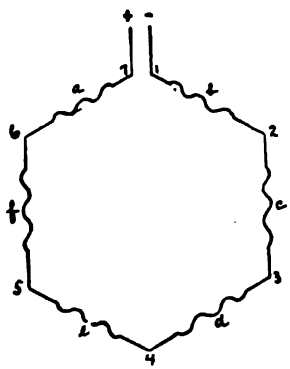


FIG. 333.—Testing for Fracture in Field Winding.

If the fracture is outside, it is comparatively easy to repair, but if internal, the coil would probably have to be rewound. Excessive vibration sometimes carries away the connections between the spools and they are apt to break off under the outside layers.

To Test for Magnetism.

Magnetism can be detected by any magnetic material, such as a piece of iron or steel or iron tool, as screw-driver or knife, being approached to a supposed magnet. Magnetism will be shown by the iron held in the hand being attracted, requiring at times considerable force to hold it away from the magnet. To detect very weak magnetism a small compass needle is used, being deflected by the very faintest trace of magnetism.

The polarity may be determined by the compass needle, by remembering that like poles repel and unlike attract.

To Test for Speed.

This is done by the use of a tachometer, which by applying its shaft to the shaft of the rotating armature indicates at once the number of revolutions. Or a speed indicator is applied to the end of the armature shaft and the number of revolutions made in a given time is counted.

To Test for Heat.

Under the table of faults, by far the greatest number of faults fall under the general head of heating, such as heating of armature, heating of commutator, heating of field coils, heating of bearings, and even the faults due to excessive current and excessive sparking are mostly faults due to the heat produced by them.

Remarks on Heating.

The expression excessive heat is one that requires a little more definite limits, for what might seem excessive to one might not be to another.

The amount of heat that is allowed in the armature coils and field windings above the temperature of the surrounding air is limited by specifications, but the degree of heat that is positively injurious is easily determined by feeling the various parts. If the heat in any part of the winding is greater than the hand can stand for a few seconds, then it is higher than a safe limit. If the hand can stand the heat for two or three minutes, it is usually not considered excessive. If there are any signs of smoke or smell of varnish or shellac or rubber, the temperature is far too high. The only way to cool heated parts is to stop the machine, except possibly in the case of bearings, where water might be used.

For accurate results as to temperature, the thermometer should be used on the parts, the bulb covered with waste and the highest reading recorded taken. To find the heat or temperature in the field windings, calculations should be made from the cold and hot

resistances by knowing the per cent increase per degree rise of temperature.

In considering the heat in any portion of a machine, it is very necessary to locate the exact source of the heat. Every or any hot part may not be the real cause, but the heat may have been conducted there from other places. A hot bearing might make a hot commutator or armature and vice versa. In locating heat troubles the very hottest parts should be sought, as they are very likely to be the source of trouble. If a certain part heats under certain conditions, it is likely it will do so again under the same conditions. To discover the parts that heat first, it is better to start with the machine absolutely cool in all its parts, and then after a short run to feel all over for the hot parts, for in a short run, there will not be time for the heat formed to be conducted to other parts. After a long run, only general temperatures can be obtained, but it cannot be told with certainty just what the source of heat is, for there is a general distribution all over the machine.

CHAPTER XXXIII.

TELEPHONES.

The underlying principle of the telephone is *the increase or decrease of intensity of an unbroken electric current,* and in order to transmit sounds of the voice over an electric conductor it is necessary that a current be caused to flow in the conductor and that the intensity of the current is in accord with the vibrating movements of the sound-producing body.

FIG. 334.—Simple Telephone Connection.

The early invention of the telephone is illustrated in Fig. 334. In its simplest form it consists of a *permanent bar magnet A, A'* at each end, with one end of each surrounded by a coil of fine wire *B, B'* in series with the line connecting the stations. A soft-iron diaphragm *C, C'* is mounted close to one end of each of the magnets. When a sound is made in front of the diaphragm, it vibrates in exact accordance with the sound waves striking against it. The vibrations produced by the voice are transmitted by the air to the diaphragm and this latter vibrates back and forth in front of the magnet. These vibrations of the diaphragm produce backward and forward movements of the lines of force which pass into the diaphragm and which are due to the permanent magnet. The magnetic field between the pole of the magnet and the diaphragm is shown in Fig. 335.

Some of these lines of force cut across the coil *B,* first in one direction and then in the other and induce currents in it. These

very feeble currents are transmitted by the line to the other end, where those in one direction pass around B' in such a direction as to *increase* the strength of the permanent magnet A', and the attraction which it exerts on the diaphragm C is thus increased. Opposite currents pass around B' in the reverse direction and *weaken* the magnet A', diminishing the attraction on C'. When C moves in one direction, C' moves in one direction and when C moves in the opposite direction, C' reverses its direction. One therefore vibrates in unison with the other and the receiver sends out waves exactly like those that fell upon the sender, and a sound made at C is reproduced at C'.

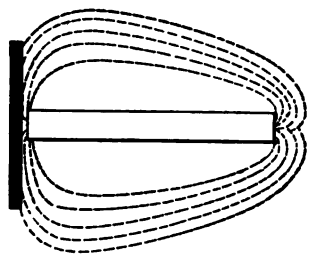


FIG. 335.—Magnetic Field at Telephone Receiver.

As long as sound waves impinge against C, alternating currents of varying intensities pass over the line and increase or decrease the strength of the permanent magnets. No battery is used in this circuit, the only currents being the induced currents caused by the lines of force cutting across the coils on the ends of the magnets, and which are so feeble that only the most sensitive instruments can detect them.

Variable Resistance Transmitters.

The source of the induced currents in the simple telephone circuit above described is due to the energy of the sound waves, and in consequence of which they are very feeble and such a transmitter could have no practical value except for very short distances. The early experiments to secure a practical transmitter were along the lines of causing variation in the strength of current produced by some outside means, the variation always remaining in accordance with the movements of the diaphragm. A battery was used and the transmitter was so designed as to cause variation in its current strength by changing the resistance in the battery circuit.

Edison Transmitter.—One of the first practical transmitters was devised by Edison and carbon was the substance by which the resistance of the circuit was varied. Carbon pieces in contact vary in their electrical resistance according to the pressure with which they are held together. The first type consisted of a platinum disc secured to the diaphragm bearing against a button of compressed plumbago. The circuit was completed through this contact which was varied by greater or less pressure on the plumbago button caused by variations in the sound waves striking the diaphragm. This change of resistance caused variations in the current that passed over the line to the receiver.

Hunning's Transmitter.—In Hunning's receiver the variable resistance medium consists of a quantity of finely-divided carbon granules held between two conducting plates, and through which the battery current flows. This form has a large number of imperfect contacts and the change in resistance is caused by the change in the pressure with which the granules are held together. The diaphragm is so arranged as to press more or less against these carbon particles and thereby produce changes in resistance which cause currents of varying intensities in the line.

Nearly all successful transmitters are modifications of this type.

Hughes' Microphone.—This type of sound transmitter or sound multiplier depends on the variations in resistance of an electric circuit caused by *loose contact* of electrodes. The elementary principles are illustrated in Fig. 336.

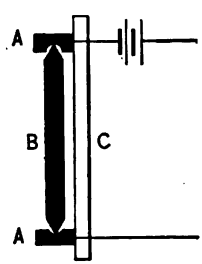


FIG. 336.—Hughes' Microphone.

C is a sounding board holding two cup-shaped contacts *A, A* of carbon, between which lightly rests a carbon strip *B*, which makes imperfect contact at *A, A*. These are connected to a battery in which a receiving instrument is included. The slightest noise, imperceptible to the unaided ear, sets up vibrations which disturb the contact of *A* and *B*, and so sets up variable currents in the line which are reproduced in the receiver with great distinctness. The clearness and distinctness of the sounds vary with the pressure, and as this is gradually increased,

the sounds become weaker, though always clear, until when the contact is perfect the sound ceases.

This indicates that it is not the resistance of the carbon itself which changes under pressure, but the change of resistance is caused by the imperfect contact at the carbon electrodes.

Of the different theories advanced for the explanation of the change of resistance of carbon under pressure, the most probable one is that the change of resistance is due to the variation of the area of contact, and in the granular form it is the variation in the number of granules in contact. An increase of pressure increases the area of contact, lowers the resistance and allows greater current to flow, while a decrease of pressure produces the opposite effect.

Carbon Transmitters.

Of the variable resistance transmitters mentioned in the preceding section, those made on the principle of the Hunning's transmitter have been the most successful, for no substitute for carbon as the variable resistance medium has been discovered. Carbon has all the properties requisite for telephonic or microphonic work; it produces change of resistance by surface contact; can be easily made into the desired form; it does not oxide or corrode; it is abundant and cheap.

The form of transmitter almost universally used in this country in the early days of telephones was the **Blake transmitter.** In this a platinum pin is pressed by a light spring against a polished plug of *hard* carbon, forming an imperfect, delicate contact through which the current flows. This mechanism is mounted behind the usual disc which takes up the vibration of the voice, and greater or less pressure is brought on the contact of the platinum pin and carbon, the varying resistance producing the requisite varying intensity of the line current.

This transmitter is very delicate and transmits the quality of the voice in an excellent manner, but it lacks in power.

Many forms of the carbon granular type have been made, and although all present peculiarities, the general principle of construction is the same, and a description of one will render clear the action of the others. The type of transmitter in general use by the

American Bell Telephone Company is known as the **White transmitter**, and is spoken of as a "solid-back" type. Its general construction is shown in Fig. 337:

The front, *A*, is of metal, forming with the back, *B*, a complete metallic casing for the working parts of the instrument. The diaphragm, *D*, is of aluminum, held by a soft-rubber ring *E*, and

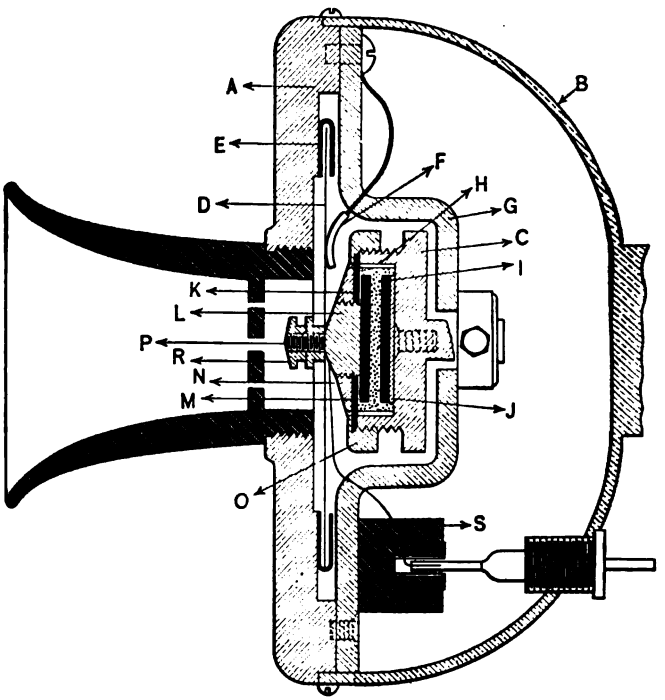


FIG. 337.—White "Solid-Back" Transmitter.

against which are held two damping springs, *F*, only one of which is shown. *C* is a metallic block, hollowed out to form an enclosure for the electrodes, and is held rigidly in place by a supporting bridge, which is secured to the metal front piece. The inner circular wall of *C* is lined with paper, and screw-threaded into its inner face is a metallic piece, *I*, against which rests the back electrode of carbon, *J*. The front electrode, also of carbon, *K*, is

carried on a metallic piece, *L*. On the flange of the piece, *L*, is carried a mica washer, *M*, held in place by the screw nut, *N*, and the washer is of sufficient diameter to cover the cavity in the block, *C*, when the front electrode is in place.

The space between the two electrodes is filled with granular carbon, and as the electrodes are slightly smaller in diameter than the cavity, the space around them is also filled with the granules. There is sufficient space left to allow for the expansion of the granules due to the heat of the current, and this form allows a large current without undue heating.

When the carbon granules have been put in the cavity and the front electrode is in position, the mica washer is slipped in and the nut, *N*, is screwed in place; after which the cap, *O*, is screwed on, binding the washer firmly against the face of the block, *C*, and confining the granules in the cavity.

The screw-threaded portion, *P*, of the piece, *L*, passes through a hole in the center of the diaphragm and is held in place by the nuts, *R*. The vibration of the diaphragm is conveyed to the front electrode, which can move against the elasticity of the mica washer, while the back electrode is firmly held, and thus more or less pressure is brought to bear on the carbon granules between them.

The back electrode is in metallic connection with the back of the instrument which forms one terminal, while the other terminal is mounted on an insulating block, *S*, and is connected to the front electrode by a flexible connecting wire.

Receivers.

The typical form of telephone receiver is shown in the elementary sketch in Fig. 334, and it might be said that the receivers used in modern practice are but developments of the single permanent magnet, with one end wound with a coil of fine wire.

In the first days of telephone work, the receivers were of the single-pole type. In general they consisted of a compound bar magnet formed of two pairs of magnetized steel bars, placed with their like poles together. Between the bars at one end is clamped a soft-iron pole piece, and at the other a similarly-shaped iron block. The soft-iron pole piece forms the core of a coil of wire

which is slipped over it, and near this coil is secured the vibrating diaphragm. The whole is mounted in a conveniently-shaped rubber shell, formed of two pieces, one enclosing the magnets, and the other screwing into it and holding the diaphragm in place. Heavy leading-in wires run from the coil along the inside of the rubber shell to terminal pieces at the bottom which project through and form outside terminals to which the line wires are connected.

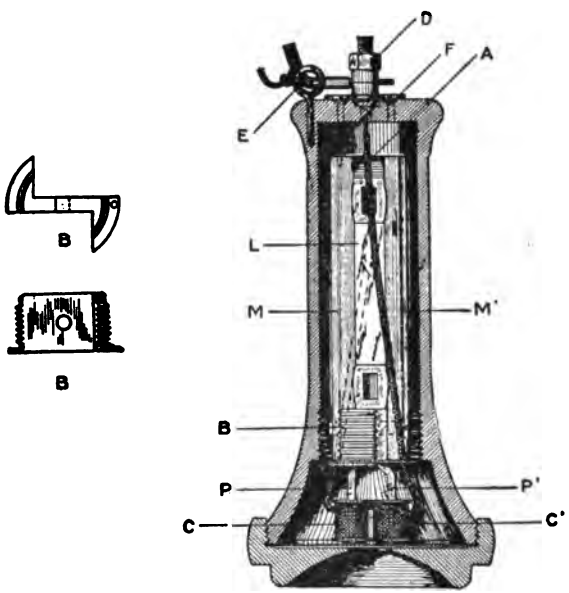


FIG. 338.—Bell Telephone Receiver.

Bipolar Receivers.—The object of bipolar receivers is to strengthen the field in which the diaphragm vibrates by presenting both poles to the diaphragm, and the lines of force are concentrated near the point where they are most effective. There have been as many different forms of receivers made as transmitters, but the governing principle remains the same, and the construction of one successful receiver will illustrate all the principal points. Such a form used by the Bell Companies is shown in Fig. 338.

In Fig. 338 are shown two magnets, *M* and *M'*, secured at one

end by screws through an iron tail block, *A*, and at the other end by a threaded brass block, *B*. The pole pieces, *P*, *P'*, carry the coils, *C*, *C'*, and are clamped between the pole end of the magnets and the block, *B*. This block screws into a threaded portion in the rubber body of the shell and by turning it the magnet poles are moved nearer to or farther from the diaphragm, and after once being adjusted, it is held by a pin through the shell. The binding posts, *D*, are fitted with lock-nuts and there is an eyelet, *E*, fitted to take the strain cord, so no strain will come on the terminals if the receiver should happen to fall. In order to give sufficient weight to properly work the hook switch, a lead weight, *L*, is clamped between the magnets. The diaphragm is secured between the two pieces of rubber shell.

Watch-Case Receivers.—In some classes of work it is necessary to hold the receiver constantly at the ear, so that the hands may be free, as in wireless telegraphy, fire control or switchboard work. For such purposes a special form of receiver that can be held in place over the ears has been devised and from its shape and small weight it has been called the "watch-case" or "head" receiver.

These are fitted with either one or two receivers, to cover either one ear or both, and are made with straps to go over or around the head to hold them securely in place.

The permanent magnets are circular in shape and of the ring type and are cross magnetized to produce poles on opposite sides of their circumferences. Circular pole pieces which carry the coils are secured to the ring magnet and their pole faces rest close to the diaphragm as in the ordinary receivers. The working mechanism is mounted in a hard-rubber shell and the diaphragm is secured between this shell and the ear piece.

Use of Induction Coils.

The first practice in connecting telephonic instruments was to connect the transmitter, the receiver and battery at one station directly in the line leading to the other station, considering for the present but two stations. The change in resistance of the whole line, whereby currents of varying intensities were produced to actuate the receivers was caused by the change of resistance in the

transmitter. In case of a long line this change of resistance was very small in comparison to the whole resistance and the currents were consequently very feeble. To remedy this difficulty, Edison proposed to use an induction coil with the primary in the circuit of the transmitter.

The connection of the induction coil is shown in Fig. 339.

T represents the transmitter in series with the battery B and the primary I' of the induction coil, I'' the secondary of the induction coil is in series with the receiver R and the line L_1L_2. The transmitter in this connection is operating in the low resistance of the primary circuit, rather than over the resistance of the whole line,

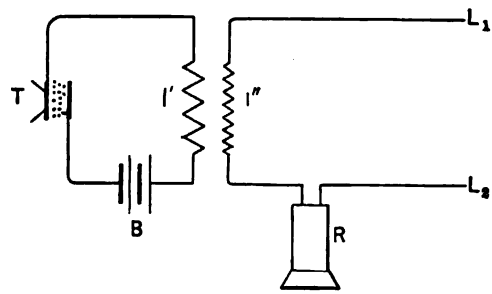


FIG. 339.—Connection of Telephone Induction Coil.

and any change of resistance caused by the transmitter bears a much larger ratio to the resistance of the primary circuit than it does to the resistance of the whole line, consequently, for the same voltage, the changes of current will be proportionately larger in the primary and the induced currents in the secondary that pass over the line will be proportionately greater. The fluctuations of current produced by the induction coil are many times greater than could be produced by the transmitter alone.

Another advantage of the induction coil is that the primary being of few turns while the secondary is of many, the induced currents in the secondary have a very high voltage as compared to those in the primary, and transmission can be effected over much greater length of line and over much higher resistance than if the transmitter was used alone.

Calling Apparatus.

Before conversation can be carried on between points, there must be some means adopted by which a person at one station can attract attention at the other. Ordinary vibrating call bells or buzzers are used, fitted with separate lines and batteries, or the talking battery may be used over separate lines, or over the talking lines. For long distances, ordinary batteries will not furnish sufficient current to operate call bells, and in some cases, they have been used with induction coils, using the high voltage of the secondary windings to furnish the desired current.

In many systems, especially in that known as the local-battery system, a form of generator is used that is very similar to the magneto shown in Fig. 316, Chapter XXIX. This furnishes alternating currents of high voltage and actuates a vibrating bell at the called station.

In central stations using the "local-battery" system attention is called by the ringing of the call bell, and at the same time by the dropping of a shutter which indicates the number of the calling station.

In the "common-battery" system, the attention of the operator is called by the lighting of an incandescent lamp by the operation of the caller removing the receiver from the hook.

Local-Battery System.

This system, as its name implies, has a local battery at each station to furnish the talking current. The system is classified under two heads, **series** and **bridging**. The series system is used when a number of instruments are used in series on the same circuit, and the bridging system where the instruments are placed in multiple or bridged across the line. This last is the more common practice.

The calling and talking apparatus operate over the same line, and when the circuit is complete for one operation it must be open for the other and vice versa, and means must be provided for effecting this result. It is now universally accomplished by a switch actuated by the weight of the receiver, and when the receiver is hanging in its provided place, the talking circuit is cut out and the calling circuit is closed ready to operate for calling.

At each station in this system there must be provided the transmitter, receiver, induction coil, battery, switch, bell and generator. It is customary to place the generator, the bell, the switch and the induction coil in one box and the battery in a separate box.

The connections for a complete station on the bridging system is shown in Fig. 340.

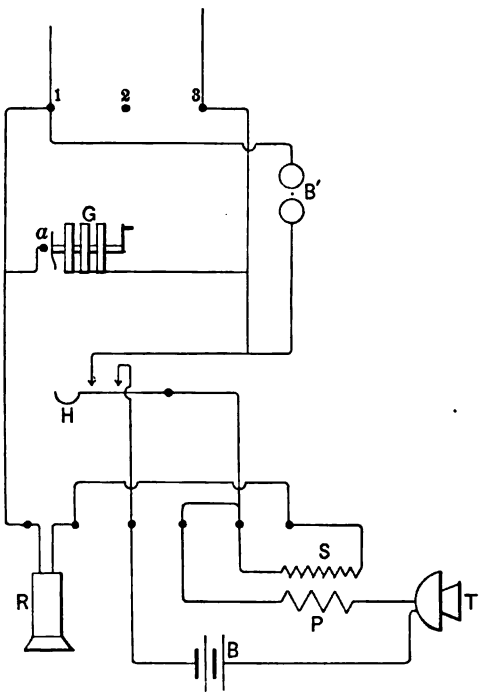


FIG. 340.—Bridging Circuit.

In Fig. 340, *R* is the receiver; *T*, the transmitter; *B*, the battery; *P*, the primary of the induction coil; *S*, the secondary; *B'*, the bell; *G*, the generator; *H*, the hook switch, and 1, 2, 3, the terminals. The line terminals are connected to 1 and 3. The position of the hook switch, *H*, shown, is accomplished by hanging the receiver on it. In this position it will be seen that the talking battery is cut out and the circuit open, and the station is ready for a call. The

bell, B', is bridged directly across the line and incoming current finds but the one open circuit, that through the bell. The generator, G, is across the line, and its circuit is broken at a, but is made by the operation of turning the handle of the generator.

To call from this station, it is only necessary to operate the generator and current goes over the line past the bell terminals to the called station, the talking circuit being open. After being called; to talk, it is only necessary to lift the receiver from the hook switch and the battery terminals are connected through the transmitter and the primary of the induction coil. The terminals of the secondary are connected by the same operation to the line through the receiver.

The above description is that of an ordinary "wall set" connected on the multiple or bridge system. In the series system, the call bell is connected to the line when the receiver is on the hook, and is cut out when the receiver is lifted clear.

The connections for "desk sets" are practically the same as for the "wall sets," different dispositions being made of the induction coil, calling apparatus and battery.

Common-Battery System.

In the Local-Battery System, it is usual to make use of the magneto for calling central, but in the Common-Battery System signals are made by simply lifting the receiver from the hook and replacing it. In some types of signals, lifting the receiver has the effect of lifting a target within sight of the operator and holds the signal displayed until the receiver is hung again on the hook, when the target drops in place, either by its own weight or under the action of a spring.

The modern method is to use a small incandescent lamp which is illuminated as soon as the hook is released by taking off the receiver. To signal any station from central requires some kind of a sound apparatus to attract attention, and current to operate this must come through the same line as the talking circuit. The signal apparatus must be in a condition to be energized at any time while the receiver is on the hook and consequently when there is no connection between the two sides of the line.

An alternating current provides the necessary solution of this problem, as it does not require a continuous metallic circuit, and it is practically done by interposing a condenser in series with the bell across the line. This bell is energized by a magneto at the central station, the condenser allowing the alternating current produced to pass through it, while it acts to keep the current of the common battery at central open.

The illuminating lamp at central may be placed either directly in series with the common battery and the line, or in a relay circuit, which is thrown in only when the battery circuit is established by lifting the receiver. In the former case, the resistance of the signal-bell magnets is sufficient to prevent enough current from flowing to illuminate the lamp, but when the receiver is

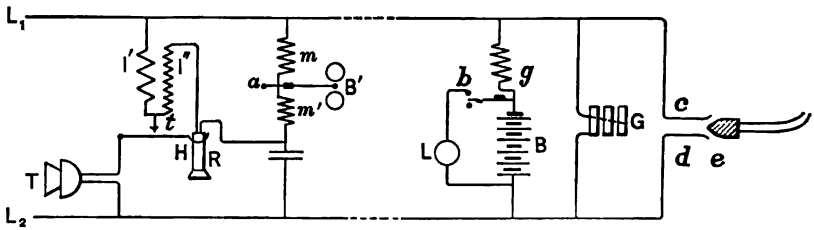


FIG. 341.—Common-Battery Telephone Circuit.

raised, the battery current flows through the low resistance of the transmitting circuit and produces sufficient current to light it.

As the name of this system implies, there is but one battery and that is installed at the central. This battery furnishes current for talking as well as for the signal apparatus at the central.

The complete connections from a station to central are illustrated in Fig. 341.

The station on the left (Fig. 341) represents one station and that on the right, the central, connected by the two lines L_1 and L_2. A battery, B, of about 25 volts is kept connected at central to all the lines entering it, but no current flows from this battery as long as the receivers, R, are on their hooks, H. In that condition there is no circuit for the direct current of this battery, as the condenser, C, acts as an infinite resistance to it. If central wishes to call the station, it is only necessary to throw upon the line an alternating

circuit which passes into and out, or through the condenser. This is done by turning the handle of the magneto generator, *G*. As the alternating current flows through the coils of the bell magnets, *m* and *m'*, the armature which is pivoted at *a* is drawn first towards *m* and then towards *m'*, vibrating back and forth between the bells *B'*, producing a ringing sound.

If the station wishes to call central, it is only necessary to lift the receiver *R* from the hook *H*. This closes the line circuit at *t* and allows current from the battery *B* to flow in the line through the transmitter. At the same time the current flowing energizes the electromagnet *g*, and its armature is attracted, closing the lamp circuit containing the lamp *L* at *b*. This illuminated lamp attracts attention of the operator who moves a switch to connect the central telephone to the calling station. As the calling station talks into the transmitter the strength of the battery current through the primary *I'* of the induction coil is varied by the varying pressure produced on the diaphragm of the transmitter. These variations induce in the secondary *I''* of the induction coil the talking currents which pass over the line to the receiver of the operator. By this arrangement the primary and secondary currents pass over the same line but it does not interfere with the distinctness of speech.

When the operator finds what station is required, it is rung up and connection is made with it by a plug *e* containing a flexible cord, which is pushed into the contacts *c* and *d*. When the conversation is over the receiver is replaced on the hook which breaks the battery circuit and the lamp at central is extinguished. The operator then disconnects the two stations.

Switchboards.

Telephone switchboards are used for interconnecting telephone lines centering at a common point. The two general systems, Local-Battery or Magneto System and Central-Battery System require each a different arrangement of the talking and calling apparatus, though they contain certain parts that are common to each.

The terminals of all lines entering the exchange at the switch-

board are secured to **spring jacks,** by which the line may be connected to another by the insertion of a plug in the jack. These jacks are small switch sockets, and so arranged that both lines of the metallic circuit are continued in a flexible cord by the insertion of the plug. This is generally accomplished as follows and can be seen in Fig. 342. One terminal of the line is secured to a circular ring which forms the socket for the plug, and the other terminal ends in a spring contact. The plug is so constructed that its tip end makes contact with the spring contact of the line terminal while the body of the plug forms a sleeve and makes contact with the ring socket. The tip and sleeve of the plug are insulated from each other and the terminals of the flexible cord are secured, one to each.

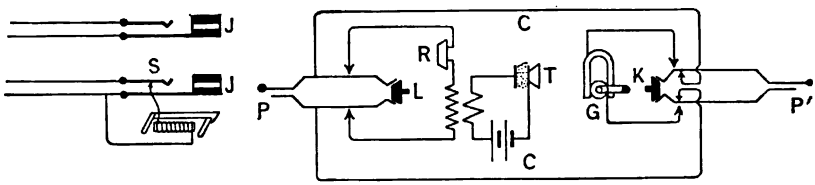


FIG. 342.—Magneto Switchboard.

Cord circuits are common to switchboards used with the two principal systems. Ordinarily it is a term which refers to two plugs with the connecting flexible wire and the necessary calling and talking apparatus by which an operator may answer a call or complete a connection with any line. In magneto switchboards a cord circuit consists of two plugs adapted to fit the spring jacks, with the connecting cord; a listening key by which the operator can connect the central talking apparatus so that conversation may be had with either one or both communicating stations, and a ringing key by which the central magneto is connected to one of the plugs and the station whose jack is plugged may be called.

Magneto Switchboard.—The essential parts of a magneto switchboard are shown in Fig. 342. The lines on the left are those from distant stations and all end in the spring jacks, *J, J.* In the lower line is shown the calling apparatus with which each line is provided. It consists of an electromagnet energized by currents produced by

the generator at a calling station, which pass over the line and around the electromagnet. When the core becomes magnetized, it attracts its armature, shown to the left, and which is pivoted at the upper end and connected to the rod above the magnet. This rod ordinarily holds in place the front target which is hinged at its lower end. As the armature is attracted, the target is released and drops, exposing the number of the calling station.

The cord circuit consists of the two plugs, P and P', fitted as above described with tip and sleeve contacts to engage the spring jacks, J, the flexible cord, C, C, and the talking and calling apparatus. The general operation of calling and talking would be as follows: Suppose the lower station calls by turning his magneto handle. This throws an alternating current on the line and on the electromagnet at central becoming magnetized, the armature is attracted and the target drops. On seeing the number of the calling station, the operator pushes the plug, P, into the spring jack, J, and presses the listening key, L. This connects the operators talking circuit in series with the line circuit of the calling station and disconnects the signal circuit, by the tip of the plug raising the spring contact, S. On finding the number of the station desired, the operator pushes the plug, P', in the jack of the desired number and presses the calling key, K. This connects the central generator, G, to the line of the desired station, and on turning the handle of the generator, current is sent over the line and rings the bell at the desired station. When the calling key is depressed, the talking circuit is cut out, by means of the spring contacts shown at K, so the alternating current of the generator cannot go over the line of the original calling station. When the desired station is obtained the ringing key is raised and the two stations are now connected for conversation.

There is usually fitted, in addition, another electromagnet across the cords circuit, C, C, which is actuated by current from either station while the jacks are still plugged to indicate that the conversation is finished.

Common-Battery Switchboard.—The circuits of a modern common-battery switchboard as developed by the Western Electric Company are shown in Fig. 343. The leads L_1 and L_2 (heavy lines)

are connected to a station, and another station, which could be shown on the right would be exactly similar. The **cord circuit** for the switchboard embraces all the portion between the plugs P and P', and in addition the switchboard also embraces the circuit shown on the left under the heavy lines L_1L_2 of the calling station. A

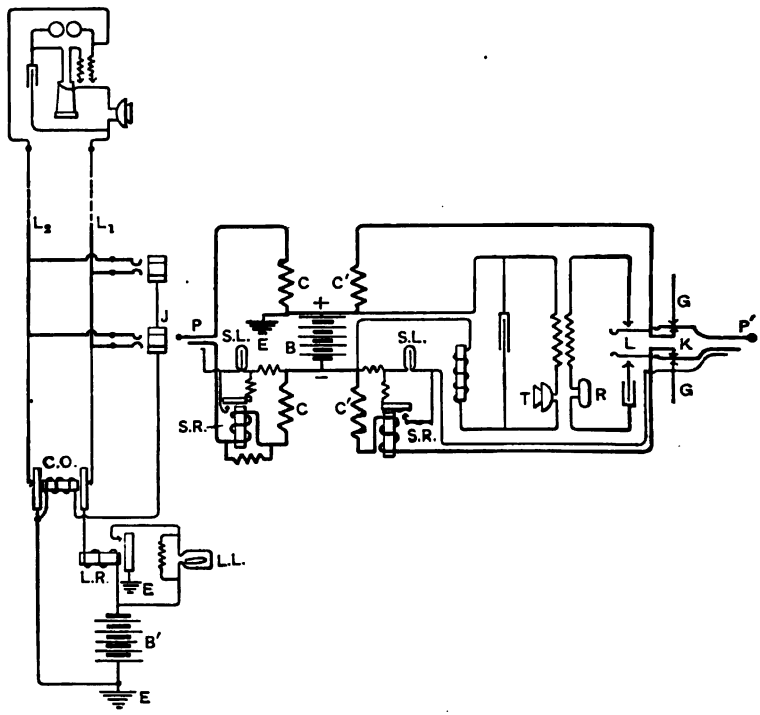


FIG. 343.—Elements of Common-Battery Switchboard. Western Elec. Co.

station on the right, or called station, would have an exactly similar equipment at the switchboard.

To signal the operator, the calling station takes the receiver from the hook. Circuit is then completed from the battery B' through the **line relay,** LR, through the primary of the induction coil at the calling station and the two armatures of the **cut-out relay,** CO. As soon as the line relay magnet is energized, it attracts its armature and closes the circuit of the **line lamp,** LL. This circuit is

completed by the armature and one side of the battery being grounded, as shown at *E*. The operation of removing the receiver at the calling station thus results in lighting the line lamp, *LL*. When the operator sees this, plug *P* is inserted in the jack, *J*, and battery *B* is thrown on the line. The plug has a third strand connected to the sleeve of the plug with connections as shown through a **supervisory lamp**, *SL*, and resistances. When the plug is inserted, current from battery *B* flows around an electromagnet, *SR*, called the **supervisory relay** and the effect is to attract its armature and cut out the lamp *SL*, through the resistance shown. Thus the supervisory lamp is not lit as long as the receiver is off the hook at the calling station.

Another effect of entering the plug *P* in the jack, *J*, is to cause the line lamp to be extinguished. This is accomplished as follows: Current from the ungrounded side of battery *B* flows through the coil of *SR*, which is then energized and attracts its armature which completes the circuit to the sleeve of the plug through the resistances in line and around the lamp. From the ring of the jack current flows around the electromagnet, *CO*, known as the cut-out magnet, to ground. This energizes the electromagnet, *CO*, and its armatures are attracted, breaking the circuit to the line relay. The electromagnet *LR* being no longer magnetized, its armature is drawn away by the action of a spring and consequently the circuit through the line lamp is broken.

When the plug *P* is in the jack and the receiver is off the hook at the calling station, current from the battery *B* is flowing through the two strands of the cord through the plug and jack over the line and through the transmitter of the calling station, thus energizing it and putting it in a condition to vary the intensity of current by the changes in its resistance caused by the sound waves striking the diaphragm.

After the operator inserts the plug in the jack, the **listening key**, *L*, is closed, which throws the central's transmitter and receiver in line with those of the calling station and conversation may be effected. When the desired number is obtained, the plug, *P'*, is inserted in the proper jack, and the **calling key**, *K*, is closed, which connects the generator circuit to the desired station, and at the same time cuts out the cord circuit to *P*, so the calling current cannot

produce any signal at the calling station. When the called station answers, the ringing key is opened which connects P' to the circuit again and the two stations are now connected through the cord circuit and conversation can take place.

When the conversation is over, the receivers are hung on the hooks at each station, with the result that the supervisory lamps *SL*, one for each station, are lighted, which allows the operator to know that the call is finished. On withdrawing the plug, *P*, the lamp, *SL*, on that side is extinguished and in withdrawing P', the one on the right is extinguished. The above operations are accomplished as follows: When the receiver is hung on the hook, the circuit of battery *B* is broken at that point, and consequently the magnet *SR* ceases to be magnetized and its armature is drawn away, breaking the shunt circuit around the lamp. Current now flows from the ungrounded pole of the battery through the lamp *SL* to the sleeve contact on the plug and through the cut-out relay to ground and to the grounded pole of the battery. Finally, on withdrawing the plug from the jack, the circuit on that side is broken and the lamp is extinguished. The same operation holds good for the station on the other end of the cord circuit.

Repeating Coils.—The coils *CC* and $C'C'$ shown in Fig. 343 are called repeating coils. Though they are shown as four separate windings, they are in reality wound on one core. The object of this winding and of inserting the battery in parallel with the talking stations is as follows: By this arrangement current from the battery divides at the junction of the coils *C* and C' and part goes to the instruments at each station and for a given difference of potential at the battery a greater current will flow in each portion of the cord circuit than if the battery was connected in series. The circuit in which change of resistance is caused by the transmitter is only that from a station to the switchboard, consequently it bears a greater ratio to the resistance of the line than if the change in resistance took place in the whole line connecting the two stations and the fluctuations of current are correspondingly greater.

A change in the current of either circuit produced by a transmitter acts inductively through the repeating coil of the other circuit and causes corresponding changes of current to act on the receiver of the other line. Thus, when the left-hand station is trans-

mitting, coils C and C act as primary coils and coils C' and C' as secondary coils, and the opposite is the case when the right-hand station is transmitting.

Interior Telephones.

Interior telephone circuits are used where a number of people located close together desire a complete intercommunication with one another. There are several systems that have been devised to meet different requirements and they are generally classified under the following heads:

1. General Intercommunicating System.
2. Common Talking-Circuit System.
3. Central Switchboard System.

In the Intercommunicating System each station can make its own connections without a central operator. This requires that at least one wire for each telephone be connected to every telephone on the system, and besides these, other wires are necessary, depending upon the plan of wiring adopted. It differs from the Common Talking-Circuit System in that as many conversations can take place at the same time as there are pairs of instruments, while the Common Talking Circuit only allows one conversation at a time.

In the Central Switchboard System the services of an operator are necessary and this system does not differ much from regular city exchanges except in the number of the telephones.

Intercommunicating System.—As an example of a successful means of interior communication, a system using the "Ness Intercommunicating Telephone" and manufactured by the Holtzer-Cabot Electric Company is given. This telephone is provided with a switch which automatically returns to the home point when the receiver is hung upon its hook.

This system is usually wired according to one of the following plans:

1. Local talking battery, central ringing battery.
2. Local talking battery, magneto ringing.
3. Central talking and ringing batteries.

Each of these plans has its own advantages, and each requires a different number of connecting wires as shown in the accompanying diagrams.

Fig. 344 shows a system using a local talking battery with a central ringing battery. In addition to a wire for each station two additional wires are required.

If No. 1 station wishes to call No. 4, the switch moving over the circular arc is moved until it rests on terminal marked 4. The button of the switch is then pressed, which rings the bell or buzzer at station 4. As soon as the receivers are off the hooks the local battery is thrown in circuit and talking takes place over the line

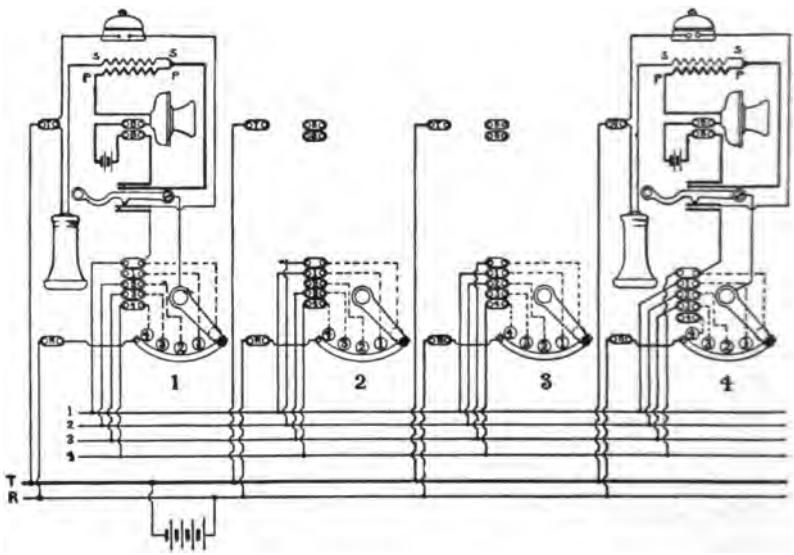


FIG. 344.—Local Talking and Central Ringing Battery.

connecting the two stations and one of the two extra wires. The primary circuit is complete through the heavy lines which include the transmitter. The secondary circuit is completed as follows: Starting from the left-hand terminal of the secondary marked *S*, current flows through No. 1 receiver, to the terminal marked *T* at No. 1, to the connecting wire marked *T*, to terminal *T* at No. 4, through No. 4 receiver, through secondary, to the hook switch at No. 4, then to the blank terminal under the ringing switch, to the blank terminal above the numbered ones, then to No. 4 connecting wire, to terminal No. 4 at No. 1, to ringing terminal No. 4, then

through the switch to the hook switch and from there to the right-hand terminal of the secondary, completing the circuit.

When station No. 1 is communicating with No. 4, No. 2 could be in communication with No. 3. As soon as the calling station has finished the conversation, the receiver is hung upon the hook which returns the calling switch to the home point, and it is now ready to receive a call from any other station.

Fig. 345 shows a system using a local talking battery with magneto call. In addition to the wire for each station, only one additional wire is needed.

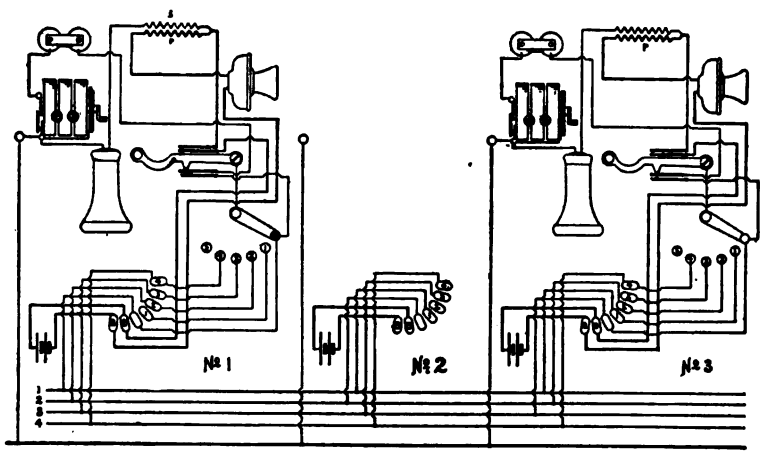


FIG. 345.—Local Talking Battery with Magneto Call.

If No. 1 station wishes to call No. 3 (Fig. 345), the ringing switch is moved to the terminal marked 3 in the curved row of terminals under the switch, and the magneto handle is turned. This throws an alternating current on the line and rings the bell at No. 3. The circuit is as follows: from the left-hand terminal of the magneto to the extra wire between stations, to the corresponding terminal of the magneto at No. 3, past the magneto and through the bell magnets, then to the terminal strip under the hook switch, to the adjoining terminal held together by the switch, to the blank ringing terminal under the ringing switch, to the blank terminal in the other curved row, then to No. 3 wire, back to No. 3 terminal in the curved row, to No. 3 ringing terminal, through the ringing

switch to the hook switch, to the terminal switch under the hook switch, through No. 1 bell and back to the magneto.

As before, when the receivers are clear of the hooks, the talking battery is thrown on the primary circuit containing the transmitters, and the talking currents flow through the wire connecting the two stations and the extra wire.

When the hook is returned to its place at No. 1 station, the switch automatically returns to the home point.

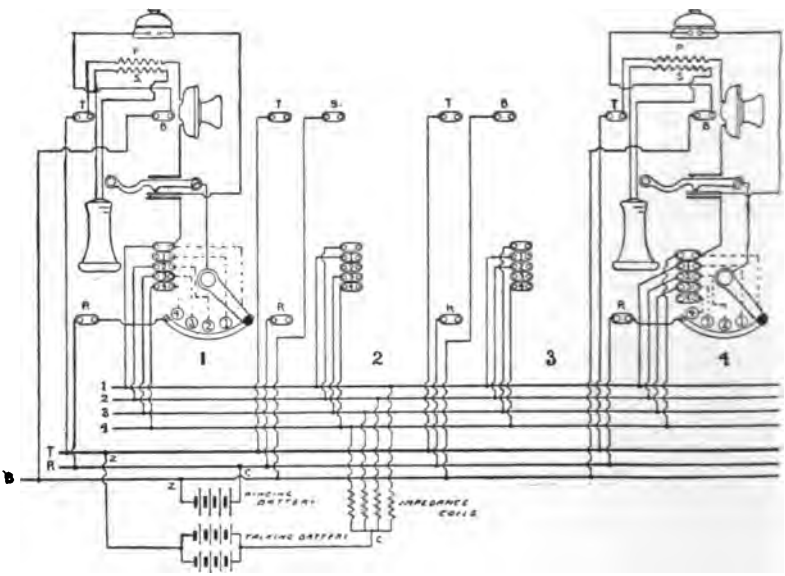


FIG. 346.—Central Talking and Ringing Battery.

Fig. 346 shows a system using both central talking and ringing batteries. In addition to the wire for each station, three extra wires are necessary.

From what has been said regarding the other two systems, this should be readily understood and the ringing and calling circuits followed. It will be noticed that the primary and secondary circuits of the talking circuit are entirely separate from each other, the current from the battery dividing and going through the primary circuit at each station. The currents induced in the secondary only flows through the receivers.

It is usual to make all the wires connecting the stations and such extra wires as may be needed in one cable, each wire being insulated from the other, and the whole completed cable insulated. The wiring from the instruments and connection terminals is made in one cable and lead to connection boxes fitted with properly marked terminals. The connecting cable between stations is then led to these terminal boxes, and connecting pieces are soldered to the wires of the cable and secured to the terminal contacts. An arrangement of desk telephone and terminal box is shown in Fig. 347.

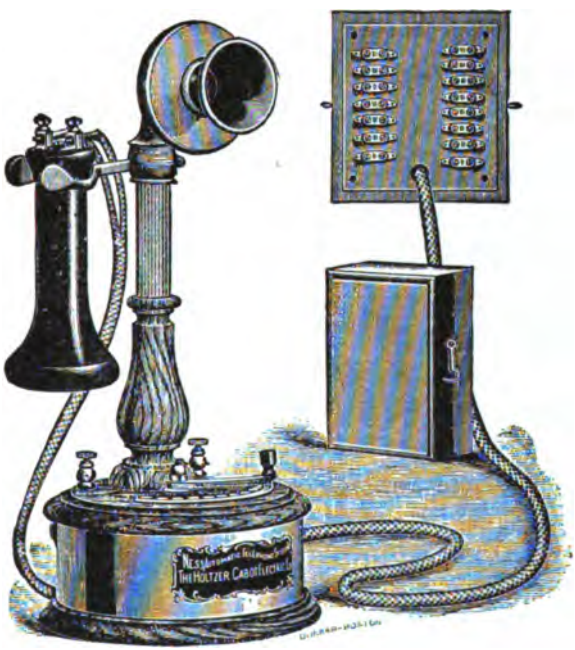


FIG. 347.—Desk Phone with Cable and Connection Box.

Navy Standard Telephones.

Telephone instruments, switchboards and typical circuits as used on board our ships of war are dealt with in Chapter XXXIV, Electrical Interior Communications.

CHAPTER XXXIV.

ELECTRICAL INTERIOR COMMUNICATIONS.

The conductors used with instruments and all means of interior communication devices are installed in conduit or molding which is in all respects like that described under Wiring Appliances.

Wiring.

Wire known as **bell wire** and **interior-communication cable** is used on all circuits, whether for generator or battery current, except where certain instruments require certain special cables. Interior-communication cable is used for all leads below the main deck, except for quarters and office calls in the non-water-tight system. In some cases this cable is used in non-water-tight sections where the leads come through a bulkhead from a water-tight section. Interior-communication cable is used also for circuits to the conning tower, chart house, military top, signal towers, emergency cabins and bridge.

All cables and wires for circuits used in action are kept below the water line as much as possible. Wires are run in conduit or molding with no more than 20 wires in any one lead.

To avoid splices and joints, connection boxes for 20 or 40 wires are used where most suitable. In these boxes the wires are clamped to terminals, affording a ready means of testing any line or branch.

Circuits used in action which are protected and which are connected to exposed circuits are provided with action cut-out switches for cutting out the exposed circuits.

All leads into wiring appliances are made thoroughly water-tight.

All wire and cable through decks or bulkheads, when molding is used, are led through standard stuffing tubes and when running through beams or bulkheads where water-tightness is not required, the hole for the lead is bushed with hard rubber.

Where wires are connected through gaskets in boxes, cut-outs or instruments, the outer braid and tape on the ends of the wire is removed, exposing the vulcanized rubber, which should never be cut into or injured.

When it is necessary to make joints in single conductor circuits it is done by first cleaning the wires, then twisting them closely together and heating sufficiently to cause the solder to flow freely into the joint. The solder used for making joints is of rosin-core type and no other flux than rosin used. All joints are taped while warm with a layer of rubber tape and covered with an outside layer of cotton tape.

Where several wires lead through tubes where water-tightness is required, the interstices are filled with rubber tape rolled spirally, especially those in the outer layer, and the whole is then wrapped with rubber tape, wrapped half its width, to completely cover the fillers, and increased at the gasket end to make it bind the wires tightly in the stuffing tube.

Conductors for Interior-Communication Circuits.

All conductors used with instruments or devices for interior communication are divided into two general classes, bell wire and cable.

Bell wire is classed as

a. Bell wire.

b. Bell cord.

Bell Wire.

Bell wire is constructed as follows:

1. A copper conductor consisting of one B. & S. G. No. 16 tinned annealed copper wire.

2. A layer of vulcanized rubber.

3. A close braid of No. 40 2-ply cotton thread, braided with three ends.

Bell Cord.—This is classed as *bell cord, double,* and *bell cord, triple.* Each conductor is constructed as follows:

Each conductor is constructed as specified for double conductor, silk, in Chapter XXVI and two or three conductors thus constructed are twisted together to form the bell cord either double or triple.

Cable.

Cable is classed as follows:

a. Controller cable.
b. Interior-communication cable.
c. Battle-order cable.
d. Range-indicator cable.
e. Powder-division cable.
f. Night-signal cable.

NOTE.—Cable classed in the above list as *a*, *c*, *d*, and *e* is not now standard, but will be found on many vessels.

Controller Cable.—Each conductor is constructed as follows:

1. A copper conductor consisting of nineteen No. 22 B. & S. G. tinned annealed pure copper wires, concentrically stranded.

2. A layer of pure Para rubber taped or rolled on to a thickness of $\frac{1}{64}$ inch.

3. A layer of vulcanized rubber to an external diameter of $\frac{8}{32}$ inch.

Seven conductors so constructed are laid up or twisted together to a circular section, six conductors lying around the seventh, and the whole is then covered with:

1. A layer of vulcanized rubber to a diameter of $\frac{31}{32}$ inch.

2. A layer of commercial cotton tape about $\frac{1}{32}$ inch in thickness.

3. A close braid of No. 30 3-ply linen gilling thread braided with three ends.

4. A close braid of No. 30 3-ply linen gilling thread braided with four ends, to a finished diameter of $1\frac{1}{8}$ inch.

This cable must show an insulation resistance between conductors and from each conductor to ground of not less than 1 megohm, 25 feet, after immersion in sea water at a temperature of 72° F. for a period of twenty-four hours.

Interior-Communication Cable.—Each unit conductor consists of seven No. 24 B. & S. G. wires, the seven grouped to approach circularity of section, the whole wrapped with No. 80 cotton thread to a diameter of 0.068 inch, then covered with vulcanized-rubber compound to a diameter of 0.136 inch, then braided with No. 60 white

cotton thread, braided with three ends, the over-all diameter 0.156 inch.

The requisite number of unit conductors is laid up with a twist (having been filled with jute laterals to approach circularity of section), then covered with:

(a) A layer of cotton tape.

(b) A layer of vulcanized rubber.

(c) A close braid of No. 20 2-ply cotton thread, braided with three ends, for all cables of less than twelve conductors, and of No. 16 3-ply cotton thread, braided with four ends, for all cables of and above twelve conductors.

(d) One unit conductor in each cable of and under seven wires, and one wire in the inner and one in the outer layer in each cable in excess of seven wires have three adjacent black threads woven in the white braid.

Dimensions of standard interior-communication cable:

Conductors.	Number of wires.				Diameter in inches.		Diameter in 32ds of an inch.	
	1st layer or core.	2d layer.	3d layer.	4th layer.	Over conductor.	Over tape.	Over vulcanized rubber.	Over braid.
3	3	.....	....	.....	.....	.3987	17	19
4	4	.....	.....	.....	.....	.4395	18	20
5	5	.....	..... .	.....	.....	.4841	20	22
6	6	.....	.. ..	.....	.....	.5312	21	23
7	1	6	.....	.....	....	.5312	21	23
8	1	7	....	.....	.....	.5785	23	24
9	1	8	.....	.....	.....	.6350	25	27
10	1	9	.....	.....	.....	.6750	26	28
11	2	9	.....	.....	....	.6875	26	28
12	3	9	.....	.....	.....	.7112	27	29
13	3	10	... .	.....	.....	.7235	28	30
14	4	10	.....	.....	.....	.7520	29	31
15	4	11	.....	.....	.....	.7729	30	32
16	5	11	.....	.....	.....	.7966	31	33
17	5	12	.....	.....	.....	.8220	31	33
18	6	12	.....	.....	....	.8430	32	34
19	1	6	12	.....	.....	.8430	32	34
20	1	6	13	.....	.....	.8800	33	35
21	1	7	13	.....	.....	.8910	33	35
22	1	8	13	.....	.....	.9325	35	37
24	1	8	15	.....	....	.9875	37	39
26	2	9	15	....	.....	1.0000	38	40
28	3	10	15	....	.....	1.0380	39	41
30	4	10	16	.. ..	.....9...	1.0645	40	42
32	4	11	17	.....	.....	1.0854	41	43
34	4	12	18	.. ..	... .	1.1345	42	44
36	6	12	18	....	.....	1.1562	43	45
38	1	6	12	19	.....	1.19125	44	46
40	1	7	13	19	.....	1.2035	45	47

UNIT CONDUCTORS (STRANDED).

Wire.		C. M.	Diameter in inches.			
B. & S.	Number of strands.		Over copper.	Over cotton wrapping.	Over vulcanized rubber.	Over braid.
24	7	2,828	.060	.068	.136	.156

Battle-Order, Range-Indicator, Powder-Division Cables.—Battle-order cable consists of an insulated stranded conductor of 38,912 circular mils cross-section, surrounded by 25 insulated conductors, each consisting of a single strand.

Range-indicator cable consists of an insulated stranded conductor of 22,799 circular mils, surrounded by 18 insulated conductors, each consisting of a single strand.

Powder-division cable consists of an insulated stranded conductor of 9016 circular mils, surrounded by 8 insulated conductors, each consisting of a single strand.

Each wire is thoroughly and evenly tinned.

The stranded inner conductor of each cable is insulated as follows:

1. A layer of pure Para rubber taped or rolled on to a thickness of not less than $\frac{1}{64}$ inch.

2. A layer of vulcanized rubber as per table.

3. A layer of commercial cotton tape, lapped to a thickness of $\frac{1}{32}$ inch.

The outer conductor of each cable consists of a No. 16 B. & S. G., insulated as follows:

1. A layer of pure Para rubber taped or rolled on to a thickness of $\frac{1}{64}$ inch.

2. A layer of vulcanized rubber.

In cables where the outer conductors are grouped in one layer, they are laid up with a left-hand twist, and when grouped in more than one layer, the layers are twisted in opposite directions, the innermost being left-handed.

One conductor in each layer is braided with No. 60 white cotton thread.

The outer layer of conductors is covered as follows:

1. A layer of commercial cotton tape lapped to a thickness of $\frac{1}{32}$ inch.

2. A layer of vulcanized rubber as per table.

3. A layer of commercial cotton tape lapped to a thickness of $\frac{1}{32}$ inch.

4. A close braid braided with four ends.

Tests.—All the tests given in Chapter XXVI on Wires are applied to Standard Bell Wire, Bell Cord, Interior-Communication Cable and Night-Signal Cable.

The requirements of insulation resistance and high potential tests are given in the following table:

	Insulation resistance.	Test voltage 30 minutes.
Bell wire	500 megohms per 1000 feet.	1500
Bell cord	No test	5000
Cable.		
Interior-communication cable:		
Between conductors	1000 megohms per 1000 feet.	1500
Each conductor to ground	1000 megohms per 1000 feet.	3500
Night-signal cable:		
Conductor for	1000 megohms per length	3500
Completed cable—		
Between conductors	1000 megohms per 1000 feet.	3500
Cable to ground	50 megohms per length	3500

Night-Signal Cable.—This cable consists of sixteen conductors made up as follows:

Each conductor is made up of nineteen strands of No. 25 B. & S. G. wire.

The insulation is as follows:

1. A layer of Para rubber $\frac{1}{64}$ inch, rolled on.

2. A layer of vulcanized rubber.

3. A layer of cotton tape $\frac{1}{32}$-inch thick.

4. A close braid of No. 30 3-ply linen thread braided with two ends.

Sixteen conductors so constructed are laid up in the finished cable.

The cable is constructed as follows:

1. The heart of the cable consists of a continuous length of 9-

thread, tarred, well-stretched hemp rope, the upper end of the heart extending beyond the end of the cable conductors and finished with a neat, strong eye splice 3 inches in length.

2. Around the heart are laid five of the unit conductors with a spiral lay and left-hand twist, and of a pitch to closely assemble the conductors on the heart.

3. On the inner lay is laid the remaining eleven unit conductors, with a spiral lay and right twist, and of a pitch to closely assemble the conductors on the inner lay.

4. The conductors are branched out for the lamps in pairs, using adjacent conductors and the reduction caused by the branching is made a neat taper by filling in with dead wire or jute. The branching is first done from the outside layer and are spaced 12 feet distance between lantern centers.

5. The outer layer of conductors is securely hitched with marline hitches, 1 inch apart, using a 6-ply flax twine of about $\frac{1}{8}$ inch.

6. The keyboard end of the cable is fitted with a standard male coupling.

General Means of Interior Communication.

The general means of interior communication controlled by electric currents are divided into the following classes:

1. **Call-bell circuits.**
2. **Telephone circuits.**
3. **Telegraph circuits.**
   a. Engine.
   b. Helm.
4. **Indicator circuits.**
   a. Engine revolution.
   b. Helm.
5. **Fire-alarm circuits.**
6. **General-alarm circuits.**
7. **Warning-signal circuits.**
8. **Battle and range-order circuits.**
9. **Fire-control circuits.**

Call-Bell Circuits.

The call-bell circuits comprise:

a. Quarters and office calls.

b. Voice-tube calls.

The quarters call generally includes all calls for use of the commander-in-chief, the captain, wardroom officers and under this special calls, as for the executive, navigator, chief engineer, surgeon and marine officer; junior officers and warrant officers.

Office calls usually include calls in the offices of the executive officer, navigator and paymaster, these being on the wardroom circuit.

Voice-tube calls are installed at each voice tube, a return call being installed at each end of continuous tubes.

Batteries for Quarters and Office Calls.—The circuits for quarters and office calls are divided into separate circuits; thus all the calls for the use of the commander-in-chief are grouped on one battery, those for use of the wardroom on another and so on. The batteries are placed in battery lockers having a separate partition for each cell, the standard size inside measurement being $4\frac{3}{4}'' \times 4\frac{3}{4}''$. There is a partition on the front of the cells to prevent their falling out when the door is opened. The door is provided with a snap catch and a name plate indicating the name of the circuit which the battery supplies.

Bell Work.

For ordinary calls for attracting attention installed on shipboard, the electric bell or buzzer is commonly used, and the working of an electric bell requires a complete electric circuit from the source of current through the bell and back to the source. The circuits in a call system are composed entirely of insulated conductors, no part of the ship being used as part of the current path. In order that the call can be made at will and that the circuit shall be left open till needed it is necessary to introduce a switch in the circuit, this being accomplished by the ordinary push button.

Typical Simple Bell Circuit.—A simple call-bell circuit is shown in Fig. 348.

B is the battery, *C* the bell and *P* the push button. The action of an ordinary vibrating bell is so well known as to require no particular mention. Closing the circuit by pressing *P* causes the circuit to be completed through the electromagnet of the bell, in which the make and break of the current causes the hammer to vibrate, producing a continuous ringing as long as the circuit is closed.

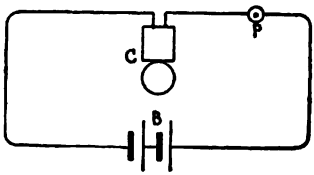


FIG. 348.—Bell Wiring.

The object of the wiring of all bell circuits is to produce a definite result with the least expenditure of conductors, and a few examples of connection will be shown to illustrate the general principles.

To Ring Two or More Bells in Different Places from One Button. —This may be accomplished by connecting all the bells in parallel from the mains containing the battery and button, as shown in Fig. 349.

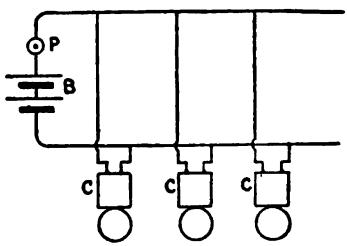


FIG. 349.—Bell Wiring.

Pushing the button causes current to flow through all the branches containing the bells and each bell will have the same difference of potential at its terminals.

Or, the bells, button and battery may all be connected in series as shown by Fig. 350, provided certain modifications are made in the bells.

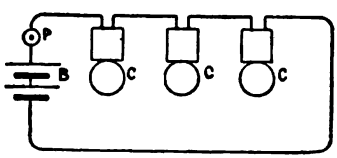


FIG. 350.—Bell Wiring.

In this arrangement all but one bell must be changed to a single-stroke bell, so that each impulse of current will produce only one movement of the hammer. The current is then interrupted by the vibrator of the remaining bell, the result being that all the bells will ring with full power. To cut out the circuit breakers on all but one bell it is only necessary to connect the ends of the magnet wires directly to the bell terminals.

To Ring One Bell from Two or More Places.—This may be accomplished by placing the buttons in the different places in parallel with the mains containing the battery and bell, as shown in Fig. 351.

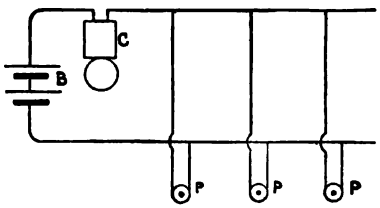


FIG. 351.—Bell Wiring.

Pushing each button completes a circuit, so the same bell may be rung from widely different places.

Annunciator Systems.

This is but an elaboration of the last examples of wiring, buttons being placed in widely different places which, when one is pressed, closes the circuit and rings a bell at some convenient point, at the same time, by a mechanical or electrical device, indicating the location of the button.

A typical annunciator system is shown in Fig. 352.

In this, one side of each button is connected to a battery wire *b* and the other to a separate leading wire *l*, in communication with the drop on the annunciator corresponding to the button. There must be one wire from each button to the annunciator, but the other side may be connected to a common battery wire or to a common return, and it is in the connection to the common return where the saving in copper arises.

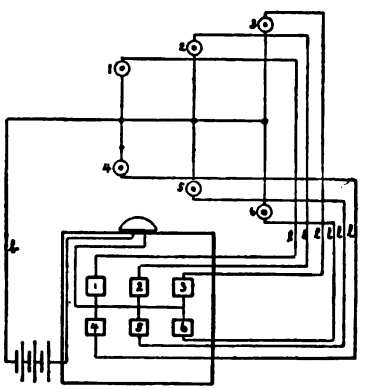


FIG. 352.—Annunciator Wiring.

It is sometimes the practice, however, to run call mains throughout the length of the ship, especially if it be a small one, and from these mains are taken off different circuits as may be necessary; single-bell circuits, annunciator circuits, alarm circuits, etc. The following figure represents such an arrangement, being an example actually installed in a small vessel.

a and *b* (Fig. 353) represent the terminals of a double-pole double-throw switch, by which current for the mains is taken,

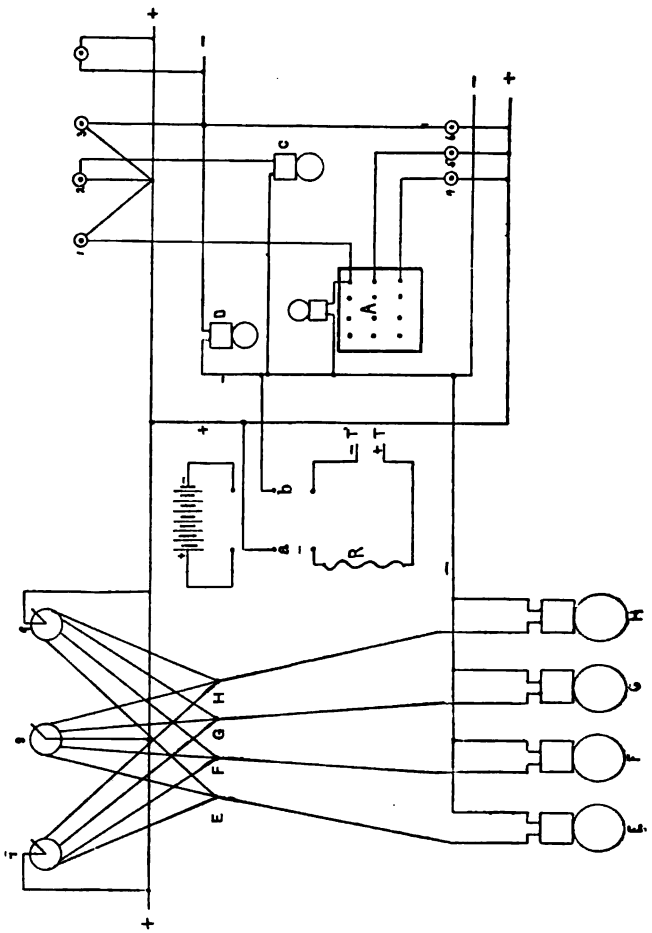


FIG. 353.—General Interior Wiring.

either from the generator mains *T* and *T'* or from the battery *B*. *R* is a resistance introduced in the generator circuit to reduce the E. M. F. of the generator to that of the battery. 1, 2 and 3 repre-

sent push buttons on the upper deck, 1 connecting to the annunciator *A* in the wardroom, 2 to a boat bell *C* in the wardroom and 3 to an orderly's bell at *D*. Buttons 4 and 5 represent buttons in the wardroom state-rooms connected to the annunciator and 6 in a room to call the orderly at *D*.

E, F, G and *H* represent alarm gongs connected in parallel between the mains through the contact points, *E, F, G, H*. These gongs are partly electrical and partly mechanical, electricity only playing the part of setting the mechanical gear in operation by which the gongs are continuously rung till the spring actuating the mechanism is run down. Only a momentary current is needed in each gong, the energizing of an electromagnet starting the mechanism. There are three gong pushes represented at 7, 8 and 9, in each of which there are four contact points connected with *E, F, G,* and *H*. A small crank turns a switch connected at the center to one of the mains and it passes over the contact points. As it does so it makes the circuit complete through each gong, so they are each independently energized and their mechanism started. All four gongs can thus be started from any one of the buttons 7, 8 or 9, which may be widely separated from each other.

This figure is intended to show some of the ways of connecting up different circuits and in which ingenuity in saving wire is a prime factor. Of course, with the energized mains any number or kind of circuit may be taken off, the principle of which is illustrated in these cases given.

Annunciator Wiring.

The general scheme adopted is shown in Fig. 354.

E represents the battery; *A*, the annunciator; *B*, a bell; *B'*, a buzzer, and *P*, pushes. One battery wire, the positive (usually white cable) leads to the bells or buzzers; a section wire, as at 6, leads from the bell to its push button and from that by the negative wire, common return, to battery. In the annunciator, a section wire is connected to the spring contact of the electromagnet for the particular station, the other terminal of the electromagnet being connected to the wire leading from the annunciator to the bell. The circuit is complete then through battery, positive wire, bell, lead

through annunciator, section wire, push button, common return (negative) to battery. In this particular system, pushes 1, 2 and 3 are in widely different places, 4 and 5 are in close proximity, needing but one drop on the annunciator, hence but one section wire; 5 and 6 are in the same place, 5 going to the annunciator and 6 to a separate buzzer. This wiring illustrates the saving of copper leads, as one wire to the common return from 5 and 6 is all that is necessary, and the common return may be a long distance away.

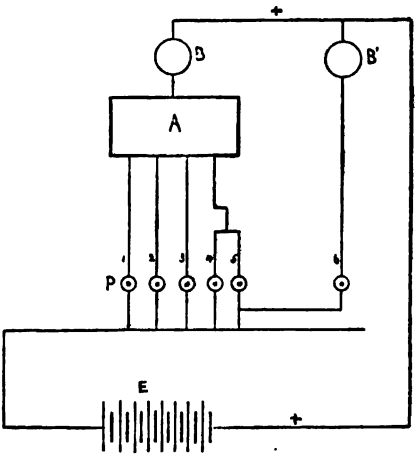


FIG. 354.—Annunciator Wiring.

Another annunciator system could be installed between the + and — leads, the wiring in all respects being the same as in the above.

The section wires may enter many connection boxes in their leads and terminals are soldered to the ends stamped with the letter showing the circuit to which each section belongs and a serial number designating the particular station to which it leads. This leads to a ready means of recognition for purposes of testing or repair.

Batteries Used with Bells and Buzzers.

For a non-water-tight buzzer without annunciator, about five Leclanche cells in series are required.

For the same with annunciator, about eight are required.

For a water-tight bell and buzzer without annunciator, about eight cells.

For the same with annunciator, 10 to 12 cells.

Call Bells, Buzzers and Annunciators.

Call bells and buzzers are of two general classes, water-tight and non-water-tight. Those of the water-tight type are of standard navy type, the non-water-tight simply good commercial types.

The **water-tight bell** consists of a yoked horseshoe magnet mounted in a water-tight composition box, the pole piece screwing into the magnet core through the outside of the box and made water-tight by lead washers. The armature is mounted on the outside of the box and is pivoted at one end. The other end carries a stud which strikes a mica diaphragm on the side of the box when the armature is attracted. This stud strikes a plunger inside which actuates a make and break contact.

The armature is protected by a non-water-tight cover. The leads are brought into the box through a stuffing tube and gland in one corner of the box. The magnet box is made water-tight by a cover screwing down on a rubber gasket. The bell is carried on an extension of the box.

The **water-tight buzzer** is in all respects the same as the bell with the exception that the bell extension, the bell and bell striker are omitted.

Annunciators.—These are of three types: the non-water-tight and water-tight annunciators for call-bell and telephone systems and a special design of water-tight annunciator used in the fire-alarm system. All are of the gravity-shutter drop type, so designed to prevent the shutter from being dropped by vibrations or gun fire. The annunciator consists of a system of magnets and drops mounted in a water-tight composition box. The box is hinged in two places, the front door opening to expose the magnets and the rear one opening to expose the contact springs to which the section leads are secured. The annunciator is wired through stuffing-boxes when molding is used and tapping in conduit when that is used.

There is a separate electromagnet for each drop, being single pole, fastened to a zinc plate. When a magnet is energized it attracts its armature, which releases a shutter, this dropping by its own weight. On the shutter is marked the station from which the button is pressed.

All section wires are connected to metallic springs in the rear of box. From each spring, contact is made to one terminal of the magnet through a screw passing through the zinc plate and insulated therefrom. The other terminal of the magnet is secured to a screw in the zinc plate which forms part of the common return.

The non-water-tight annunciator is similar in its construction to the water-tight type, but is mounted in a wooden case. This type has only one door, for the purpose of examining the contact springs and connections. To get at the magnets it is necessary to unscrew the glass front.

The fire-alarm annunciator is similar to that used with the call-bell system, but with the following exceptions:

Below the drops are arranged a set of switches, one being in the section lead to each magnet. These are normally kept closed, but when the circuit through any magnet is established it should be cut out to prevent the continuous ringing of the bell. Both terminals of the magnets are insulated from the zinc plate, one being connected as before, the other to one side of the switch, and the other side of the switch connected to the zinc plate which forms part of the common return.

Faults on Annunciator Systems.—Annunciators are made so that the front may be opened, exposing the electromagnets without disconnecting any of the wires. The faults most likely to occur are grounds or leaks caused by moisture in connection boxes or by corroded contacts. The annunciator should first be tested, then the push buttons and then line. The annunciator is tested by the magneto for leaks between the terminal of the wire leading from the bell and the different section spring contacts. If a leak is found in a section, the push button should be examined, and if that is all right, the line should be examined in all the connection boxes.

The whole circuit can be tested for leaks by opening the battery switch and testing across the line terminals with a magneto, and for a ground, test from each terminal to earth. If a ground is discovered at the battery terminals, leave the switch open and test the annunciator between all the terminals and earth. If not found in first annunciator, leave it open and test the next, and so on. If the ground is not found in any of the section wires, then look for it on the battery wire leading to the bells in the connection boxes.

An annunciator bell may not ring owing to weak current, in which case the battery should be examined and tested at its terminals for voltage.

The dropping device in the annunciator may fail to work owing

to the contact maker of the bell being so adjusted that the vibration is too rapid, so that the magnet does not have time to act. This can be remedied by the tension spring. The springs of the armature clips sometimes become weak, either not allowing the shutter to drop or not holding the shutter in place.

If any moisture makes its appearance in the annunciators, it should be at once dried out. This sometimes shows on the interior of the face.

Telephone Circuits.

Several types of telephone instruments have been designed to meet the requirements of ship installation, and a few of the types in most general use will be considered.

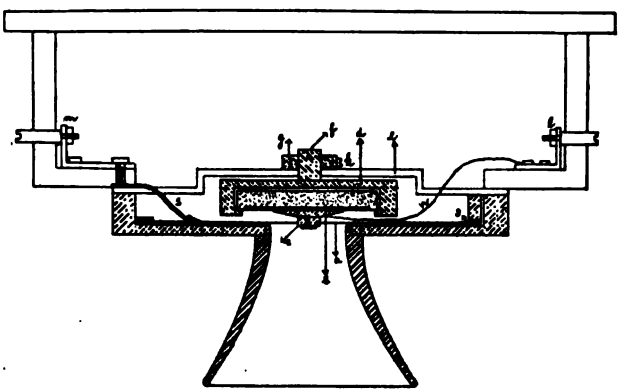


FIG. 355.—Telephone Transmitter.

Fig. 355 shows the details of one of the earlier forms of transmitters. *a* is a diaphragm of aluminum connected by the stem and nut *c* to the brass plate *b*, with base of mica set in brass box *d*. This box is filled with German silver filings. The brass box *d* is connected to the metal disc *e* by means of the stem *f* and support *g*. This metal disc is screwed to the wood of the telephone box. The flat springs *s*, *s* press with soft rubber feet against the diaphragm *a*, preventing any vibration in it except that caused by the voice.

Current from the talking battery enters the contact piece *l* through the automatic switch in the telephone box, then by the

wire *w* to the stem *c*, through the German silver filings to the metal disc *e* and out by the contact piece *m* to a terminal on the bottom of the box, then through the receiver back to another terminal on bottom of the box and thence to the other pole of the talking battery.

A receiver is shown in Fig. 356. The mechanism is encased in a rubber shell *S*, the upper part being cut away to allow the ear to be placed near the vibrating diaphragm. Inside there is a permanent magnet *P*, of a shape like the figure 6, and on the inner curl is a projection *C*, forming the core of an electromagnet whose coil is in series with the transmitter through the wires *l*, *l*. Over the core *C* is a thin iron disc or diaphragm *D*, that is attracted more or less strongly by the current in the electromagnet.

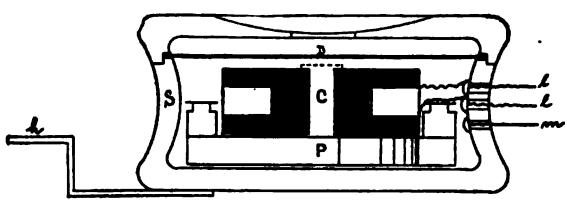


FIG. 356.—Telephone Receiver.

The receiver has a hook, *h*, by which it is hung to the automatic switch, breaking the talking circuit, and a cord *m* secured to the base of the telephone box, by which its weight is taken from the connecting wires *l*, *l*.

Cory Telephone Transmitter.—A type of transmitter extensively used, made by Cory & Son of New York, is shown in Fig. 357.

The figure shows a metal casing which forms a chamber for the microphone and damper springs which are diametrically opposite each other and insulated from the case. The diaphragm is aluminum and is attached to the upper electrode of the microphone and is pressed against a raised portion of the inner side of the circular disc which forms the top casing of the transmitter. Inserted between the top and body of the casing and over the diaphragm is a resilient water-proof material which excludes all moisture.

The lower electrode is attached to a screw which extends through the bottom of the casing and through a socket which is insulated

from the casing. A tapered thread on the outside of the socket with a nut is fitted for the purpose of locking the screw after the adjustment of the electrodes has been properly made. This adjustment is made with a screw-driver which may be used in a slot in the end of the screw.

The space between the electrodes is about two-thirds filled with hard carbon granules. A soft felt ring encircles the electrodes for the purpose of holding the carbon granules in the space between the electrodes.

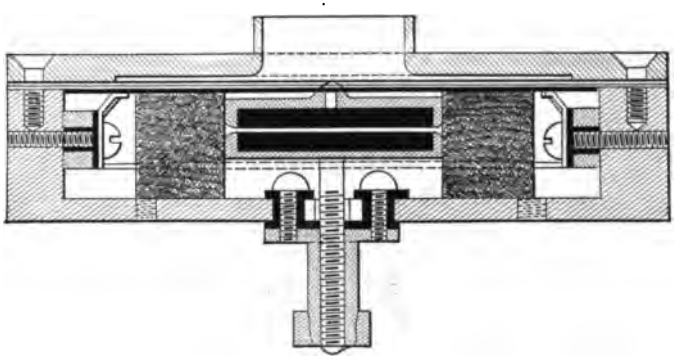


FIG. 357.—Cory Transmitter.

Electrical connection from the top electrode is made through the diaphragm and damper springs to a terminal in the bottom of the casing, and from the lower electrode to the socket around the screw to a similar terminal. These terminals are insulated from the case.

Receiver.—Fig. 358 shows a cross-sectional view of the receiver used with the transmitter described above. An annular metal case forms the chamber for the permanent and electromagnets and its top edge forms the lower bearing for the diaphragm. This is of sheet tin and is clamped between the case and the disc which forms the case cover.

The permanent magnets are compound C-shaped and are two in number, with the open end of the C towards the center of the case. Screwed to them are soft-iron extension pole pieces. The cores for the electromagnets, two in number, extend through the pole

extensions and through the bottom of the case where they are secured by a jam-nut. The lower ends are slotted so that the distance between the diaphragm and the core pieces may be adjusted by screwing them in or out without disturbing the magnet spools which fit over them.

The above-described transmitter and receiver are used in two types of instruments, one a water-tight type, the other a non-water-tight type.

Water-Tight Type A-1.—The particular characteristics of this type are shown in Fig. 359. There is a mouth piece which directs the sound waves to the transmitter in the center of the water-tight case containing all the working mechanism. In the inoperative

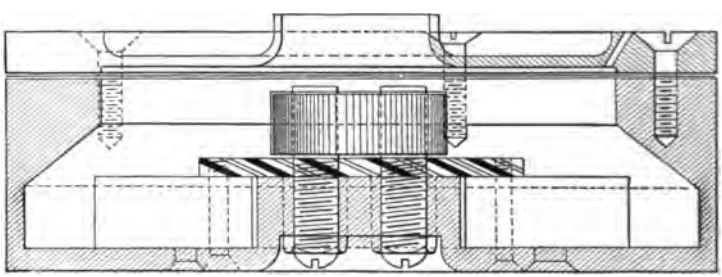


FIG. 358.—Cory Receiver.

position the opening to the transmitter is covered and made water-tight by an annular surface, which is held tightly against the base of the mouth piece by the tension of springs acting through arms, which are secured to discs on the ends of the cylindrical surface.

There are two ear pieces, one on each side of the case, connected by flexible tubing to a tee piece which is in communication with the receiver mounted at the extreme top of the case.

The connecting wires, three in number, are lead through conduit in the bottom and are connected to contact strips insulated from the case, along the inside of the back face. The connections through contact make and break switches, shown in the upper right-hand corner are such that when the ear pieces are hanging down and sprung into recesses on the outside of the case, the bell on the outside is connected to the calling circuit. To answer a call, the

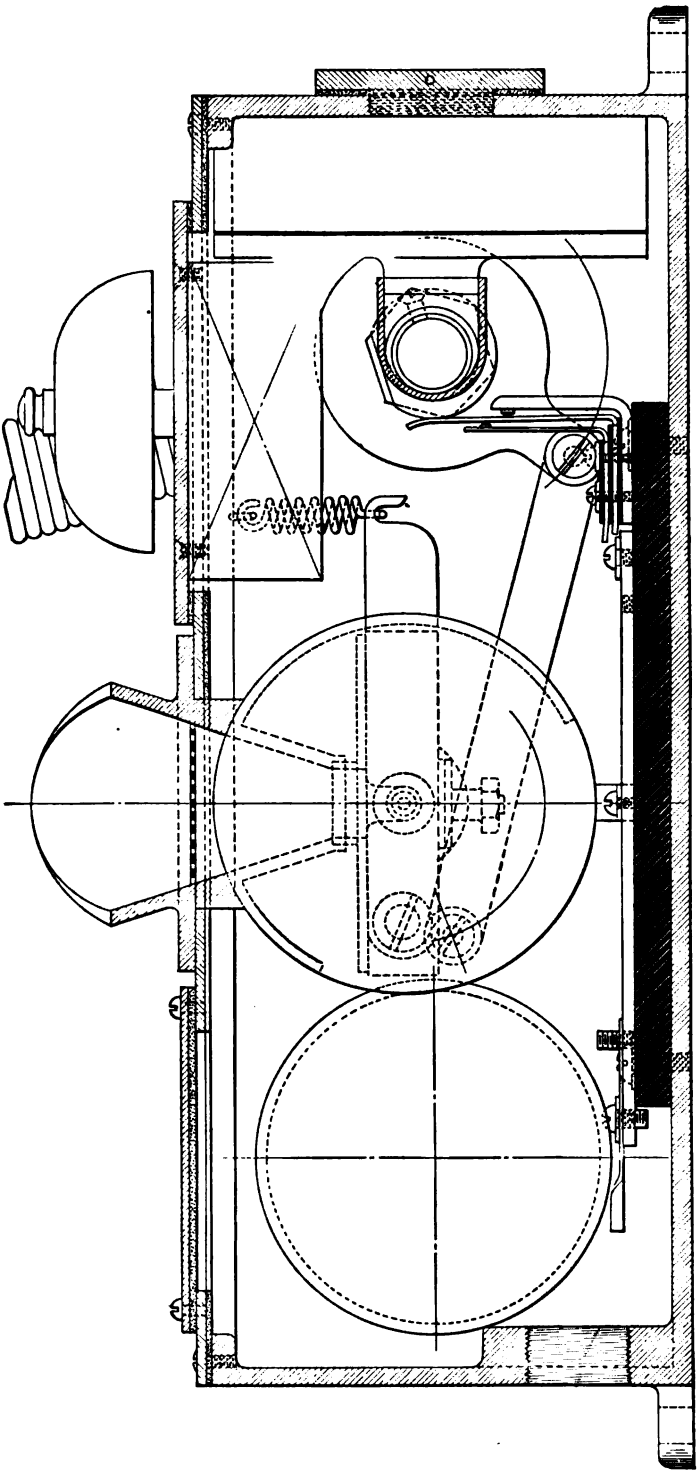


Fig. 359.—Water-Tight Type A-1 Cory Telephone.

ear pieces are sprung from the recess and are raised, this operation having the effect of breaking the bell connections and connecting the receiver and transmitter to the line. This motion also turns the annular ring spoken of above, and brings an open space in it opposite the hole in the bottom of the mouth piece, and allows the sound waves to reach the transmitter. The transmitter itself is turned at the same time, the effect of which is to cause a motion of the carbon granules and prevents their hardening or packing. This turning effect is produced by the bell-crank arm and link shown in the figure.

Connection to the transmitter is made through spring contacts from the main contact strips to projections on the trunnions of the movable discs which revolve the transmitter. This is frictional contact and allows connection while still allowing free movement of the transmitter.

The contact strips are four in number though there are but three wires for each instrument. One strip forms the neutral wire terminal and is permanently electrically connected both to the transmitter and the receiver. One is connected to the bell through a make-and-break switch when the receiver arm is in the inoperative position. Another is similarly connected to the other terminal of the bell. When the receiver arm is up the bell connections are broken and the receiver and transmitter are connected to the line. These connections are illustrated in Fig. 360.

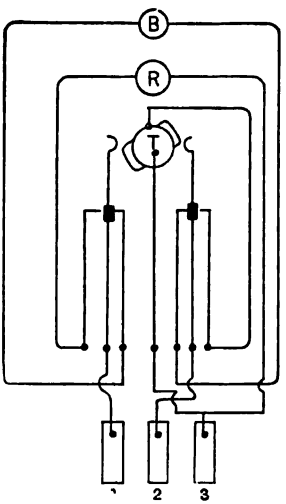


FIG. 360.—Terminal Connections.

Terminal 3 is permanently connected to both the transmitter *T* and receiver *R;* 1 is connected through the left-hand spring switch to the bell *B* and 2 is similarly connected. When the transmitter is revolved, the middle spring contacts are thrown to the right and left breaking the bell connections and connecting terminals 1 and 2 to the receiver and transmitter respectively.

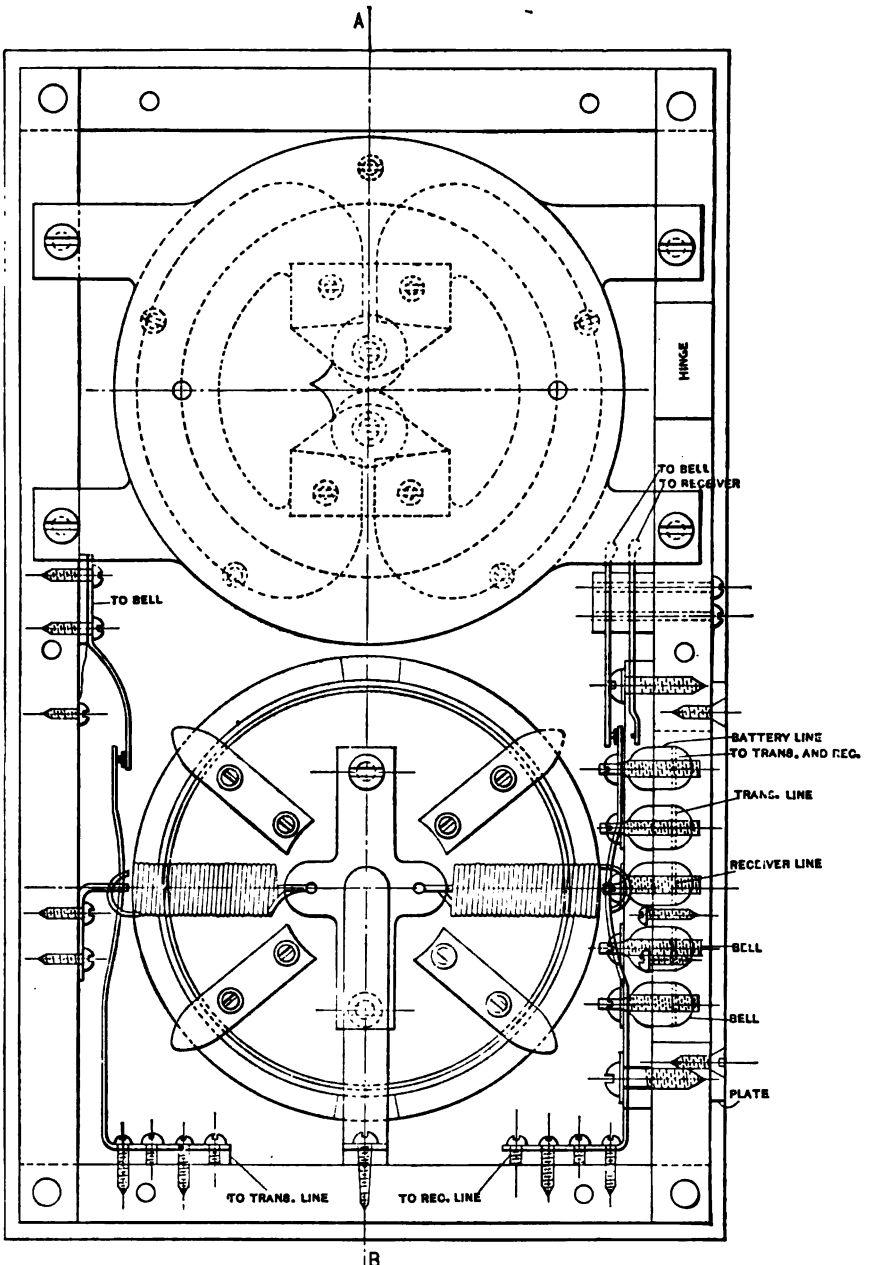


FIG. 361.—Non-Water-Tight Telephone, Showing Rear View with Back Removed.

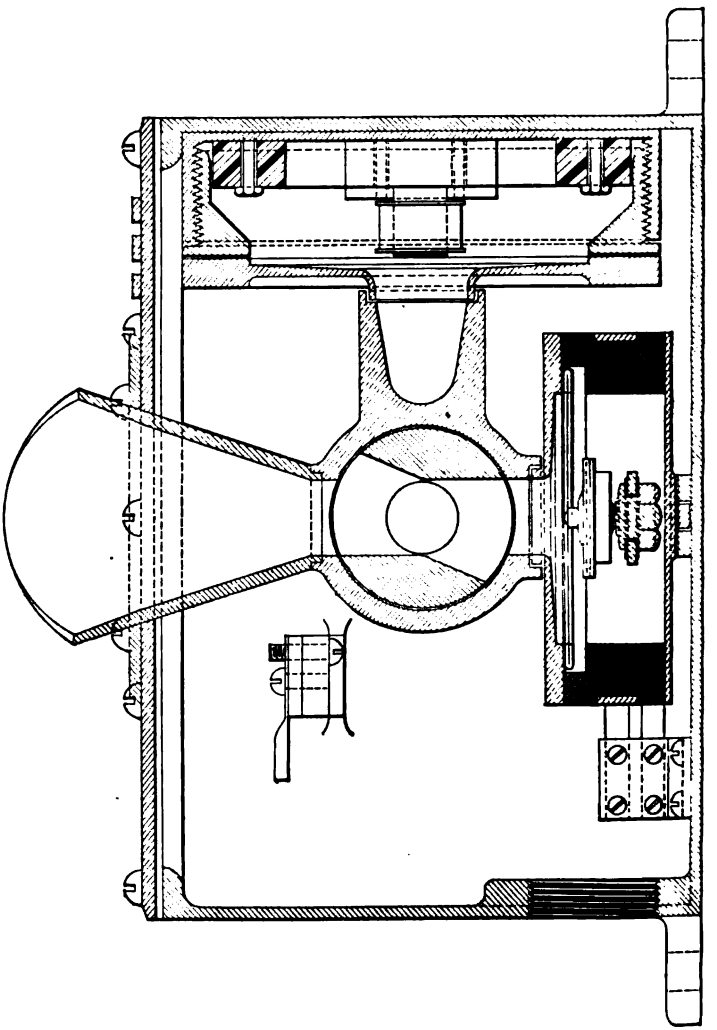


FIG. 362.—Section View of Type C-3, Cory Telephone.

Non-Water-Tight Type B-1.—The transmitter and receiver of this type are similar to those already described, but are mounted in a non-water-tight mahogany case. A general interior view is given in Fig. 361, showing the receiver mounted on the upper half and the transmitter on the lower half of the case. The sectional view of the receiver shows the C-shaped permanent magnets described under the Receiver. Provision is made for revolving the transmitter to give a motion to the carbon granules, and the connections are such that when the transmitter is held in its normal position by two heavy springs, the talking circuit is cut out, and to become operative the transmitter must be turned either to the right or left. While still inoperative for talking, the calling circuit to the bell is complete, and turning the transmitter for talking breaks this circuit and throws in the talking circuit. This operation is exactly the same as previously described, though the actual connections are different, but may be seen from an inspection of the drawing in Fig. 360.

The two left-hand lugs shown above and below the spring are electrically connected to the back of the transmitter and serve as one terminal for the transmitter, dependent on which direction it is turned. A spring contact presses against the adjusting screw on the back electrode of the microphone and forms the other terminal.

Water-Tight Type C-3.—This type also made by Cory & Son presents the peculiarities of those previously described, and in its external appearance is similar to Water-Tight Type A-1. The transmitter is somewhat different and the details may be seen in Fig. 362. Raising the left-hand ear piece has the effect of opening the mouth piece to the receiver which remains closed and water-tight when the ear piece is down in its normal position. The transmitter is turned by raising the left ear piece and it is provided with lugs on its outside periphery which actuate the spring contact pieces controlling the circuits. Fig. 360 shows how the bell circuit is complete when the arm is down and how the connection to the transmitter and receiver is made when the transmitter is turned.

Non-Water-Tight Type F.—The characteristics of this type are shown in Fig. 363. The receiver is connected to a megaphone

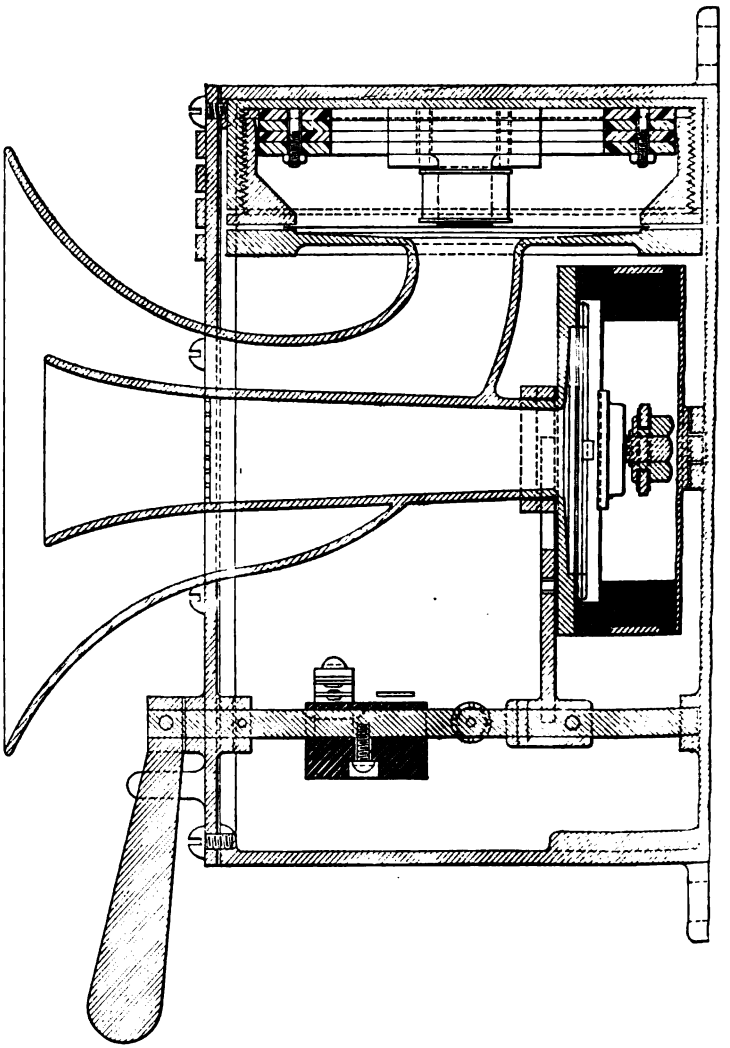


FIG. 363.—Non-Water-Tight Type F, Cory Telephone.

which entirely surrounds that of the transmitter. The transmitter is turned by the handle shown at the bottom through a toothed arc which engages a similar arc on the face of the transmitter during which the change of connections from the bell to the talking instruments is made.

Gun-Head Set.

The Standard Gun-Head Set, as made by the Holtzer-Cabot Electric Company, consists of two receivers, one for each ear and one transmitter. The receivers are mounted in a padded leather head piece so arranged as to fit tightly around the ears, front and back, with the receivers held slightly away from them. The leather head gear is held by two buckled straps over the head, one near the forehead and one over the crown, and by a strap passing under the chin. The connecting wires to the receivers are carried to a terminal piece which is secured on one shoulder, and from these terminals, flexible wires are lead to permanent terminals secured at a convenient place in the circuits of the fire-control system.

The transmitter is permanently secured in front of the mouth on two steel wires which pass across the face and around the head over the receivers. The wires are fitted with adjusting screws to suit different-sized heads and the transmitter itself is capable of adjustment in the direction of the supporting wires. The connecting wires are lead to the same shoulder terminal piece that takes the wires from the receivers.

Transmitter.—The construction of the transmitter is shown in section (right) and with the back casing removed (left) in Fig. 364. The general principles of this transmitter will be understood from the construction of the "solid-back" transmitter described in Chapter XXXIII. It consists of an enameled aluminum casing secured by three small screws to the enameled aluminum front. Screwed into the front is the nickeled-brass mouth piece, which is covered at the bottom by wire gauge soldered to it. Resting on the interior of the front is the German silver diaphragm held by soft-rubber bands and two springs shown in the left-hand figure. These springs are of steel and are screwed at one end into projecting pieces of the bridge and the other ends are enclosed in flat rubber tubes which press against the diaphragm.

Secured to the outer casing and extending diametrically across the interior is the white nickeled-composition bridge which forms the solid back for the transmitting devices and holds the terminals for the leading-in wires. Between the bridge and the diaphragm is the aluminum cup which contains the supports for the electrodes, the electrodes themselves and the carbon granules. The electrode supports are of brass and are fitted with screw spindles at their centers, one of which screws into the bushing in the center of the bridge, and the other passes through the center of the diaphragm where it is secured by a nut. The rear end of the cup is covered by

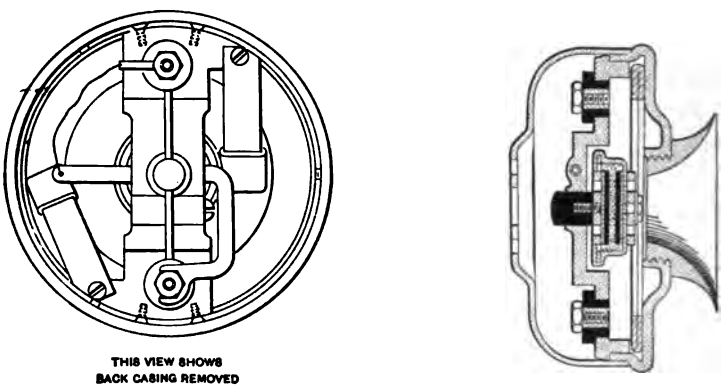


FIG. 364.—Transmitter.

a mica diaphragm held in place by an aluminum clamping ring. The electrodes are of carbon between which in the cavity of the cup are placed the carbon granules.

One electrode is connected by a thin copper strip to one of the terminals on the bridge and the other by a flat copper strip and a flexible connection to the other terminal. The leads are taken out through the middle of the back casing. These details are seen in the left-hand figure.

Receiver.—The construction of the receiver is shown in Fig. 365. It consists of a hard-rubber case made in two parts, the back case and front case; the front screwing on the back and between them is secured the diaphragm. The front is hollowed out to form a

recess to fit the ear. The back is lined with a nickeled-brass lining which contains the magnets. The magnet is a compound circular one formed of four pieces of soft steel bolted together, three of them forming little more than 270 degrees. There are two magnet coils mounted on soft-iron cores which are bolted to the ends of the magnets. The cores are mounted on zinc supports, and are bent up at right angles to the diaphragm and brought near the middle of the case. The cores are provided with both a metal and fiber washer and over them are slipped the coils of the magnets.

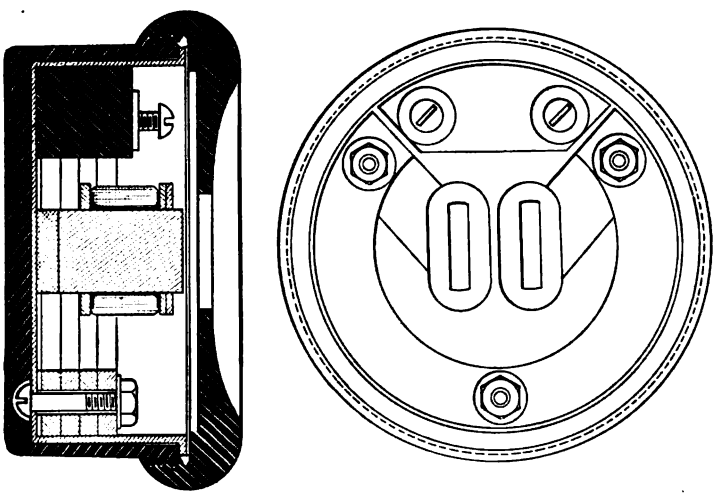


FIG. 365.—Head-Set Receiver.

Between the ends of the magnet is secured a hard-rubber terminal block held by screws to the outside casing, and to which are secured two screw terminals to which the leads from the magnet coils and to the line are brought.

Switchboard.

The general practice has been to control all telephone circuits from one general switchboard, though at present two general circuits, independent of the fire-control system, are installed; one for general use and one for the engine and fire-rooms. The general use

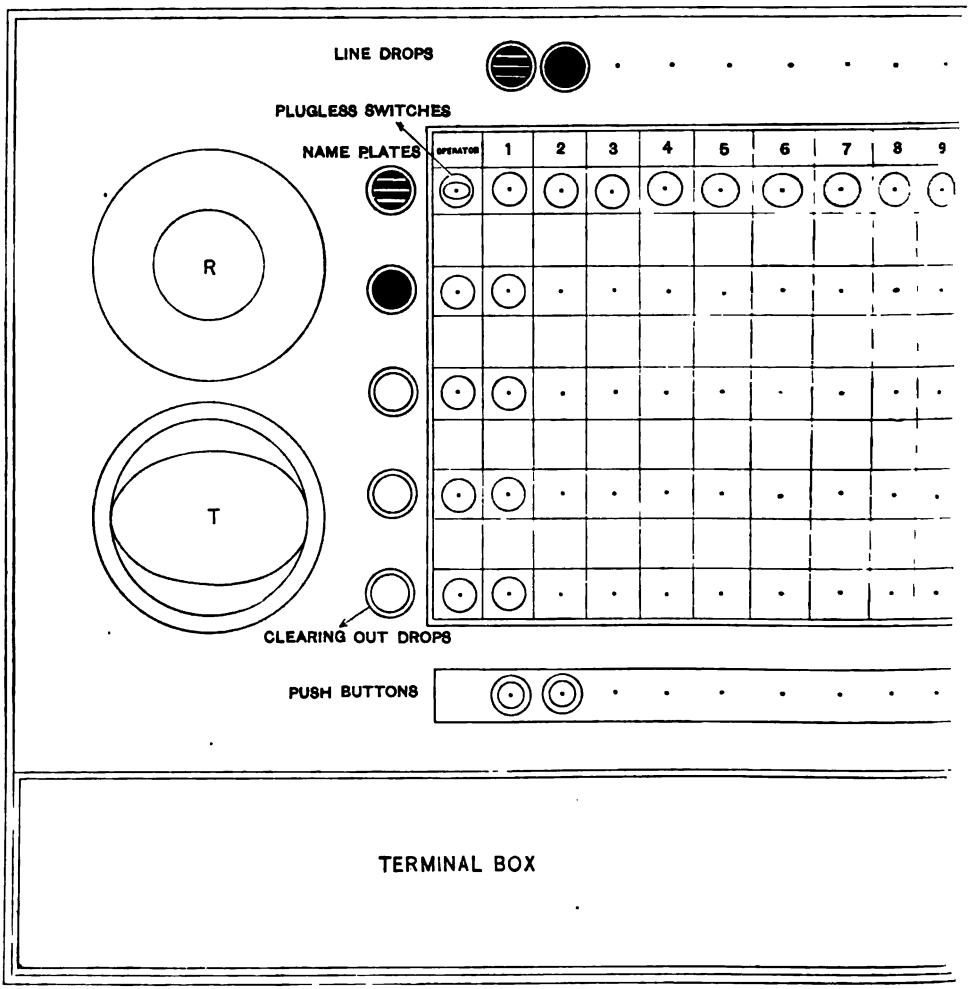


Fig. 366.—Telephone Switchboard.

circuit embraces all telephones installed in officers' quarters, offices and all stations outside of the engine and fire-rooms. The telephones on each circuit are controlled from its own switchboard.

The switchboard is constructed for a central energy system and three wires lead from each instrument to it. It is of the *plugless, cordless* type and so arranged that five separate conversations can be carried on at the same time. The elements of the standard board, made by Cory & Son, are shown in Fig. 366. The working mechanism is contained in a water-tight brass case fitted with a cover which is made water-tight by dogs. Mounted inside and hinged to the bottom is a shutter on which are mounted the plugless switches, the annunciator-target drops, the clearing-out drops, push buttons for calling, name plates, and the operator's receiver and transmitter. The drawing shows connections to nine instruments arranged in five rows and for each extra station a separate vertical strip containing a line drop, name plate, switches and push button would be added. Two stations in any horizontal row can communicate, but neither one of these two in another row can be in communication with another station at the same time as the first. Thus 1 and 2 in the first row, 3 and 4 in the second, 5 and 6 in the third, 7 and 8 in the fourth can all be in communication at the same time, but 1 and 3 in the second row could not communicate at the same time, nor 2 and 4, etc.

The line drops are of the self-restoring type, and the indication consists of three white panels showing on a normally black disc. As soon as current is cut off, they automatically restore and show as plain black discs. The clearing-out drops are of the same type as the line drops and give the same indication. When the horizontal row is clear, that is, when all telephones are in their inoperative positions, the discs show black, but as long as any instrument has not been returned to its normal position, the target shows three white panels on a black background.

The push buttons are fitted one for each station for the purpose of allowing the operator to call up any station.

Connection is made by the operator to any station or between any two stations by means of plugless switches operated by levers, which are moved either up or down, one up and one down. This

breaks the calling circuit and throws in the talking circuit. The wires lead to a series of platinum-tipped contact springs, eighteen to each switch, and the contacts are closed or opened by the cam switches.

Each vertical row of switches may be separately removed by taking out the screws holding the strip and pulling on the switch levers.

A portion of the switchboard case is separated from the main body, shown at the bottom of the drawing, and forms a connection box for all the wire terminals leading from the telephones. The different circuits are carried in conduit which is tapped into the connection box, thus keeping it water-tight. The box is covered by a screwed top also for water-tightness. The terminals for the different circuits are mounted on micanite strips fastened longitudinally along the box.

Talking Batteries.—Each horizontal row is provided with a separate battery, so that conversation may be carried on between two stations in each row. These batteries are of the Gonda type and are arranged six cells in each battery. A separate spare battery is provided for each row, and five double-pole, double-throw switches are provided on the interior-communication switchboard, so that either battery may be used on the switchboard.

Ringing Battery.—On the interior-communication switchboard, there is a double-pole, double-throw switch, and on one side of the switch is provided a battery of twelve Gonda cells for furnishing the current required for ringing. The other side of the switch is connected to the intermediate voltage terminal of the dynamotor, and either source of current may be used at will.

Wiring Diagram.—The wiring of the switchboard and instruments is illustrated in Fig. 367. This shows the wiring of the operator's telephone, *O*, and two stations, *A* and *B*, for talking and one station, *A*, wired to show the calling circuits. It will be remembered that there is a separate talking battery, *TB*, for each row of horizontal switches, and conversation can only be carried on between two stations in one horizontal row, and not with one in one row and one in another. For each telephone added to the system, there would be an additional vertical row of switches, with line drop, push button and name plate.

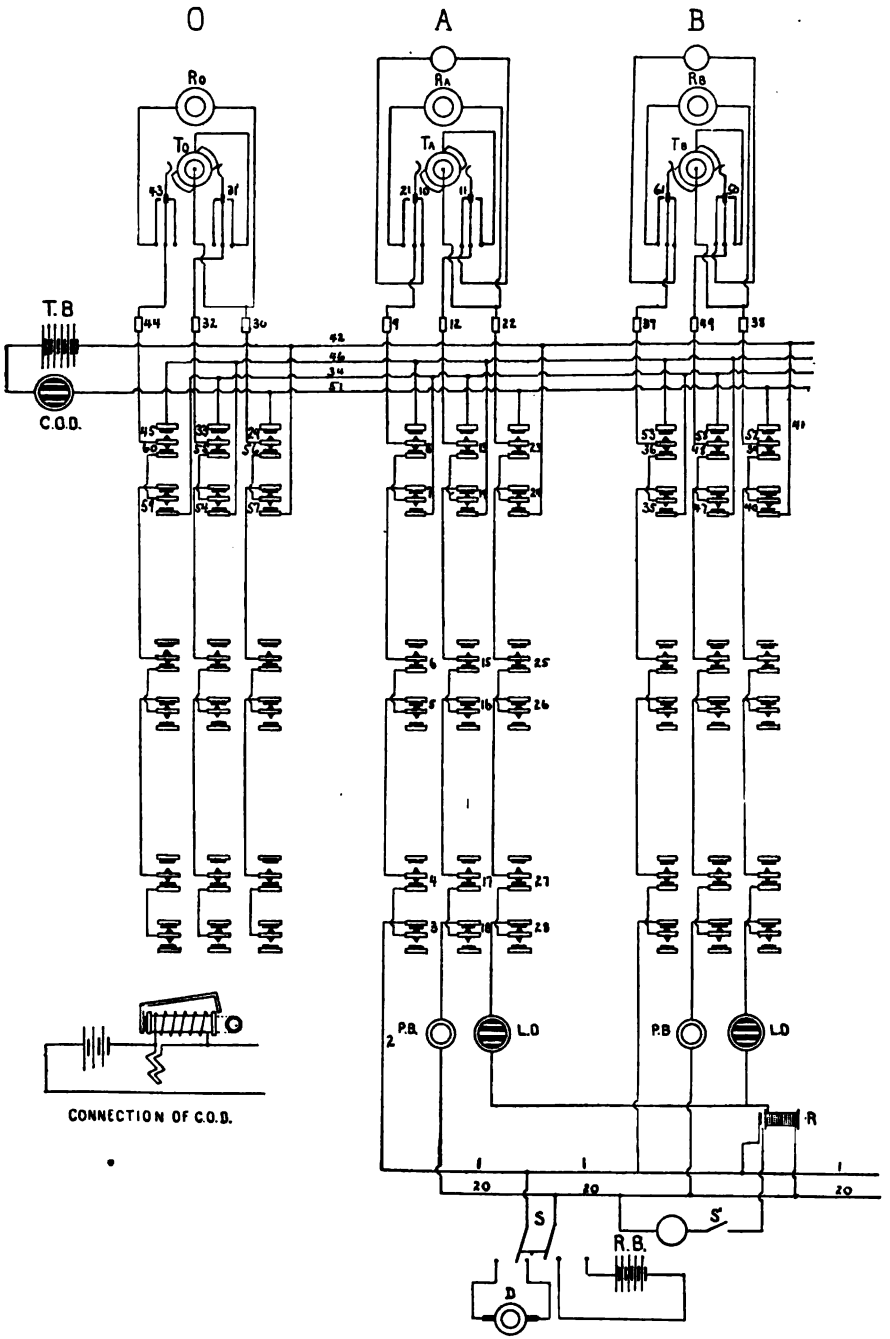


FIG. 367.—Wiring Diagram of Telephone Switchboard.

Plugless Switch.—There is a plugless switch for each telephone in each horizontal row; thus, if there are forty telephones, including the operator's instruments, connected so that five conversations can take place simultaneously, there will be two hundred plugless switches. Each switch has eighteen platinum-tipped contacts, as shown in the wiring diagram, the light lines representing the contacts and the black lines the platinum tips. The double-tipped contact is movable and can make contact to the one either above or below it by operating the lever. When the switch lever in any row is inclined *up,* the bottom row of double-tipped contacts is pushed *down,* making connection with the lowest line of contacts, and when it is *down,* the upper row of double-tipped contacts is pushed *up,* making connection with the highest line of contacts. It must be remembered that only either the upper or lower line of contacts is connected to the circuit and not both, and that when connection is made between two stations, the switch lever at one station must be up and the one at the other, down.

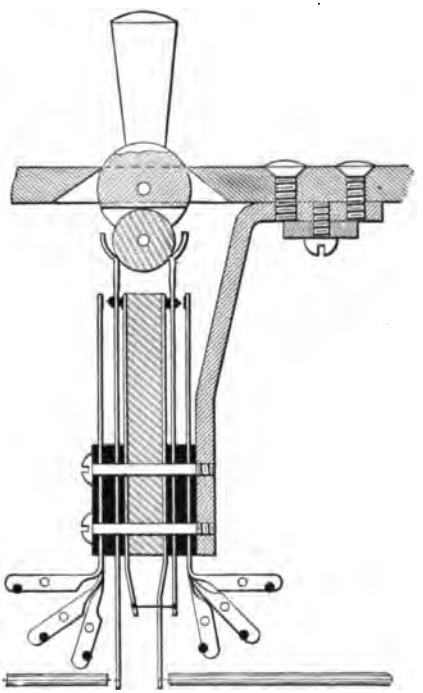


FIG. 368.—Plugless Switch.

The details of the switch are shown in Fig. 368. Six contacts are shown; the other two series of six are in line with them and are entirely similar. The three double-tipped contacts on either side of the switch lever are moved together and make connection with the three in either outer line.

The general operation is as follows: Suppose station *A* wishes

to communicate with station *B*. The one at telephone *A* revolves his transmitter, which throws current from the ringing battery *RB* or dynamotor *D* on the line and the indication is shown on the line drop over *A's* name plate *LD*, showing three white bands on the black background. The operator at the switchboard on seeing this signal moves one switch lever in the vertical row under *A's* name plate, say, up and one in his own vertical row and in the same horizontal row as that for *A*, down. He then revolves his transmitter which connects his telephone with that of *A* and communication can be effected. At the same time current flows from the talking battery through the clearing-out drop *COD* for that particular horizontal row and gives the indication of three white bands on a black background and shows that that horizontal row is busy.

Moving a switch in *A's* vertical row, either up or down, breaks the circuit of the ringing battery and the line drop restores itself to its original condition.

On learning from *A* that station *B* is desired, the operator presses the push button *PB* in *B's* vertical row which closes the ringing circuit through the bell at *B*. At the same time, the operator moves his switch to its normal position and moves a switch in *B's* vertical row, and in the same horizontal row as *A*, in the opposite direction to that of *A*. This puts *A* and *B* in communication and the clearing drop shows that horizontal row is busy, while the operator is free to communicate with another station through another horizontal row.

When *A* and *B* are finished, they return their transmitters to the original position, when the clearing drop indicates "clear" by showing its normal indication, and the operator then moves the switches to their original positions. The drop indicates clear when both or either one of the telephones are in their inoperative positions, and if one should be left connected to the line, the line drop will indicate it when the switch is returned to its normal position.

Ringing Circuit.—Suppose central wishes to call station *A*. He does so by pressing the push button *PB* for that station, and the circuit can be traced as follows: Starting from one side of the dynamotor *D* or ringing battery *RB* through double-throw switch *S*

to common wire 1, through wire 2 to contacts 3, 4, 5, 6, 7, 8, to terminal 9 on telephone *A*, to contact 10, through bell on *A*, to contact 11, to terminal 12, to contacts 13, 14, 15, 16, 17, 18, through push button to common wire 20 and to the other side of battery or dynamotor.

If an out station as *A* wishes to call central, the circuit is thus traced: As before from the battery or dynamotor to terminal 9 on telephone *A*, which has been turned to call central, then to contact 21, through receiver R_A to terminal 22, through contacts 23, 24, 25, 26, 27, 28, through line drop *LD*, through relay magnet *R* to common wire 20, to battery or dynamotor. When current flows through the relay magnet *R* it attracts its armature which closes a local circuit containing a bell, current flowing direct from the battery through the bell when the switch *S'* is closed. This acts as a night bell to attract the attention of the operator, or may be left in to be used in connection with the drop.

Talking Circuit.—Suppose the operator is connected to an out station *B* with the operator to talk to *B*, and that the operator's switch is *down* and *B's* switch is *up*. Current then flows from one side of the talking battery *TB*, through the clearing-out drop *COD*, to contact 29, to terminal 30 on the operator's telephone, through T_O, to contact 31, to terminal 32, contact 33, wire 34, contacts 35, 36, to terminal 37 on *B*, to contact 61, through receiver R_B to terminal 38, to contacts 39, 40, wire 41 to wire 42, to other side of battery.

The circuit from *B* to the operator with same arrangement of switches is to terminal 30 on the operator's telephone as before, through R_O, to contact 43, to terminal 44, to contact 45, wire 46 to contacts 47, 48, to terminal 49 on *B*, to contact 50, through T_B, to terminal 38 and back to battery as before.

With the switches reversed, that is, with operator's switch *up* and *B's* switch *down*, for the operator to talk to *B*, the circuit is: From battery through clearing-out drop to wire 51, to contact 52, to terminal 38 on *B*, through R_B, to contact 61, to terminal 37, to contact 53, over wire 46, to contacts 54, 55, to terminal 32, to contact 31, through T_O, to terminal 30, to contacts 56, 57, to wire 42, back to battery.

The circuit from B to the operator with the same arrangement of switches is to terminal 38 on telephone B as before, then through T_B to contact 50, to terminal 49, to contact 58, over wire 34 to contacts 59, 60, to terminal 44, to contact 43, through R_o, to terminal 30, to contacts 56, 57, to wire 42, back to battery.

It will be noticed in the reversal of switches results in the current flowing in opposite directions through the receivers and so changes their polarity, an effect which tends to increased efficiency of talking.

Care and Management.—The trouble that is most likely to occur in the telephone system consists of grounds, caused by moisture finding its way to any part of the apparatus or conduits. Tests for open circuits and grounds should be made daily with the magneto at the battery switchboard for both ringing and talking circuits. This can be done by testing from one of the battery switches on the interior-communication switchboard with all the switch levers *up*, and if found clear, with all *down*. If a leak or ground is shown, the switches should be opened one at a time, until the fault disappears, and that particular circuit should be disconnected and the circuit further tested by disconnecting the wires at the telephone to see if it is in the instrument or in the line. If in the line, it must be traced through each connection box.

The switchboard and interior of instruments should never be opened in search for troubles, until all other means have been tried.

Batteries should be tested each day for voltage and should be kept charged to their full capacity.

In operating the switches, they should not always be used in the same way, that is, not always up or always down, but should be interchanged, as this changes the direction of the current through the receiver, reversing the magnet polarity and improves the talking qualities.

TELEGRAPH CIRCUITS.

Engine Telegraphs.

These are installed on the bridge, in the conning tower and central station and sometimes in the chart house with indicators in each engine-room. The indicators in the engine-rooms are some-

times fitted with transmitters to return the given signal. Cut-out switches are used on the circuits to the bridge and chart house, so as to cut them out of circuit in time of action.

These telegraphs are used to signal to the engine-rooms an increased or decreased number of revolutions, usually from one to four. The telegraphs are of the lamp pattern, the operation of moving a handle on the transmitter ringing a bell at the indicator to call attention and at the same time lighting a lamp which illuminates a number indicating the number of revolutions desired.

The **transmitter** includes an indicator, both mounted in a cylindrical case on a pedestal. The dials are divided into eight segments, four for increased revolutions and four for decreased. Each lamp is in a separate compartment, so that the illumination can only show on a single number.

The calling circuit consists of an arrangement of magnetos and bells, there being a magneto at each transmitter and a bell at each indicator, and this circuit is entirely independent of the lamp circuits. The magneto bell at each indicator is wired in series with the magnetos at the transmitters, so the call is given at all indicators simultaneously. The armature of the magneto at a transmitting station is revolved by the action of the handle moving over the face of the dial, the motion being multiplied by sprocket chains operating gear wheels.

The contact maker in the transmitter consists of two carbons, one of which is always in contact with the common return wire from the lamps. The other makes contact when moved by the handle with separate strips of metal, one for each lamp, which are connected to the section wires leading to each lamp.

To send an order by the transmitter, the handle is moved all the way across the dial, this motion revolving the armature of the magneto, setting up an alternating current which rings the bells at all indicators. The pointer of the handle lever is left in the center of the division containing the required order and a clutch drops in a notch to hold it. This completes the lamp circuit through the lamp in the indicator of the transmitter and through each other indicator, illuminating the number which represents the desired order.

The indicators in the engine-rooms are similar in all respects to the indicators of the transmitters.

The lamp circuit is on the generator potential, the whole circuit being protected by fuses and controlled by a switch usually located on the interior-communication switchboard.

The wiring is all in standard interior-communication cable run in conduit, usual connection boxes being installed.

Sources of Trouble.—The magneto circuit must be carefully watched for grounds, as they are liable to occur owing to the high E. M. F. of the alternating current, but these can be easily tested for in the terminals of the magneto in the pedestal of the transmitters.

If a lamp fails to light, it may be due to a broken filament or a loose contact in the socket.

The connection boxes are the most fruitful sources of grounds, and if any appear, these should be examined first for moisture or corroded contacts.

Wiring.—The transmitters and indicators are all wired in multiple from a generator circuit. A typical circuit is shown in Fig. 369, where all corresponding wires are numbered to aid in tracing the leads and connections.

Helm Telegraphs.

These are located on the bridge, in the chart house, in the conning tower and in the central station. Receivers are provided in the tiller room, steering engine-room and at the after wheels. Cut-out switches are placed on the circuits leading to the bridge, chart house and after wheels.

These telegraphs are used to signal different helm angles to the different steering stations. Combined transmitters and indicators are installed at all sending stations and receivers, or indicators, at each receiving station.

The transmitters and indicators and the method of signaling is exactly the same as in the case of engine telegraphs, with the exception that the dials are marked to show in degrees, there usually being four signals to each side, starboard and port. The dials are marked 0°, 5°, 15°, 35°, port, and steady, 5°, 15°, 35°, starboard.

The calling circuit is the same as for the engine-room telegraphs, and the method of wiring is in all respects like that circuit. The

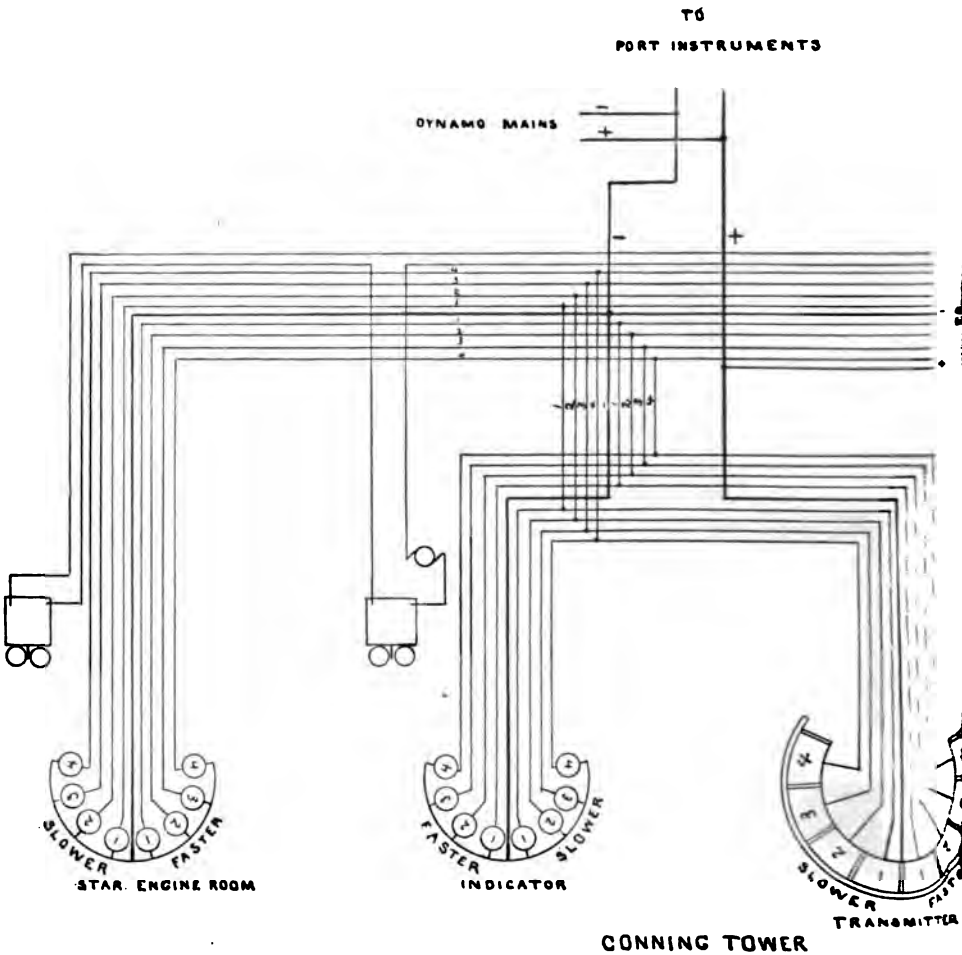


FIG. 369.—Wiring of Engine Telegraphs.

current is taken from a generator circuit, properly switched and fused.

The wiring shown in Fig. 369 illustrates the wiring of these instruments, all the instruments being connected in multiple.

INDICATOR CIRCUITS.

Engine-Revolution and Direction Indicators.

These are intended to indicate the direction of the revolution of the main engines, and by means of a watch to tell the number of revolutions in any given time.

They consist of transmitters and indicators, the transmitters installed in the shaft passages, with indicators in the engine-rooms, conning tower, chart house, on the bridge and in the central station. Cut-out switches are installed on those circuits leading to the chart house and bridge.

The **indicator** consists of a circular water-tight case with a glass front covered with a dial of white porcelain, marked "Ahead" and "Astern." Below these words are two small pointers which are given a motion of 45 degrees from the vertical by the controlling mechanism. This motion is intermittent, one motion from the vertical and back corresponding to one revolution of the engine shaft. When the engine is going ahead, the pointer under the word "Ahead" is worked by the mechanism. The mechanism consists of two complete double-pole electromagnets, one for use with the "Ahead" pointer and one for the "Astern." The circuit is made and broken by the transmitter in the shaft passage, and the magnet is alternately magnetized and demagnetized, attracting an armature which actuates the pointer.

On each shaft is secured a toothed-wheel eccentric with the shaft, engaging a smaller tooth wheel, which causes a small rod to move up and down, closing the circuit to the magnet once each revolution.

On the base of the indicator dial is a switch by which the circuit can be thrown in when indications are desired, otherwise the circuit is completely off, though the transmitter is continually working. A lamp behind the dial serves to illuminate it when required.

Wiring.—The wiring is in standard cable and connection boxes. The current is obtained from a battery of cells, ten to twelve cells being required for the indicator. The lamp terminals are connected to a generator circuit.

The wiring plan is shown in Fig. 370.

Helm-Angle Indicators.

These are intended to indicate the angle of helm, and consist of a transmitter located in the tiller-room and indicators in the steering engine-room, conning tower, chart house, on the bridge, at the after wheels and in the central station. Cut-out switches are placed on the circuits leading to the chart house, bridge and after wheels.

The indicator is of the lamp pattern and is of the same type as the indicator used in the engine and steering telegraphs, but it

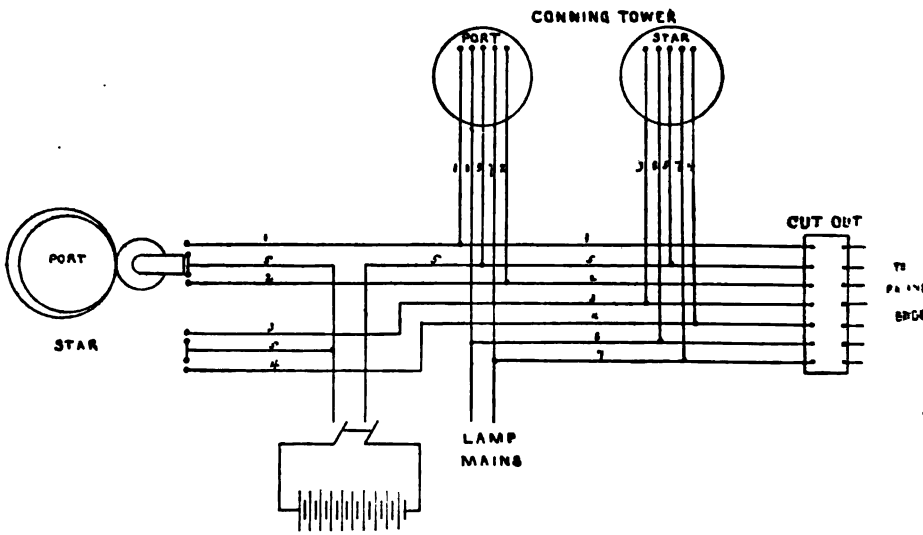


FIG. 370.—Wiring of Revolution Indicators.

contains fifteen lights instead of eight. The starboard side of the indicator shows green lights and the port side, red, the 0°, or amidships position, showing white. The dial is marked on each side $2\frac{1}{2}$, 5, $7\frac{1}{2}$, 10, 15, 25, 35, these representing the number of degrees the helm makes with the fore-and-aft line.

The transmitter consists of an arc of about 80 degrees, on which are mounted strips, one for each of the number of degrees indicated, and these are all insulated one from the other. Concentric with this arc is another solid strip, to which the common return wire is secured. These two arcs are mounted near the rudder head

and the contact maker consists of a brass arm carried by the rudder head, the arm resting on both arms, putting the section in circuit on which it rests. Putting any section in circuit lights a lamp in each

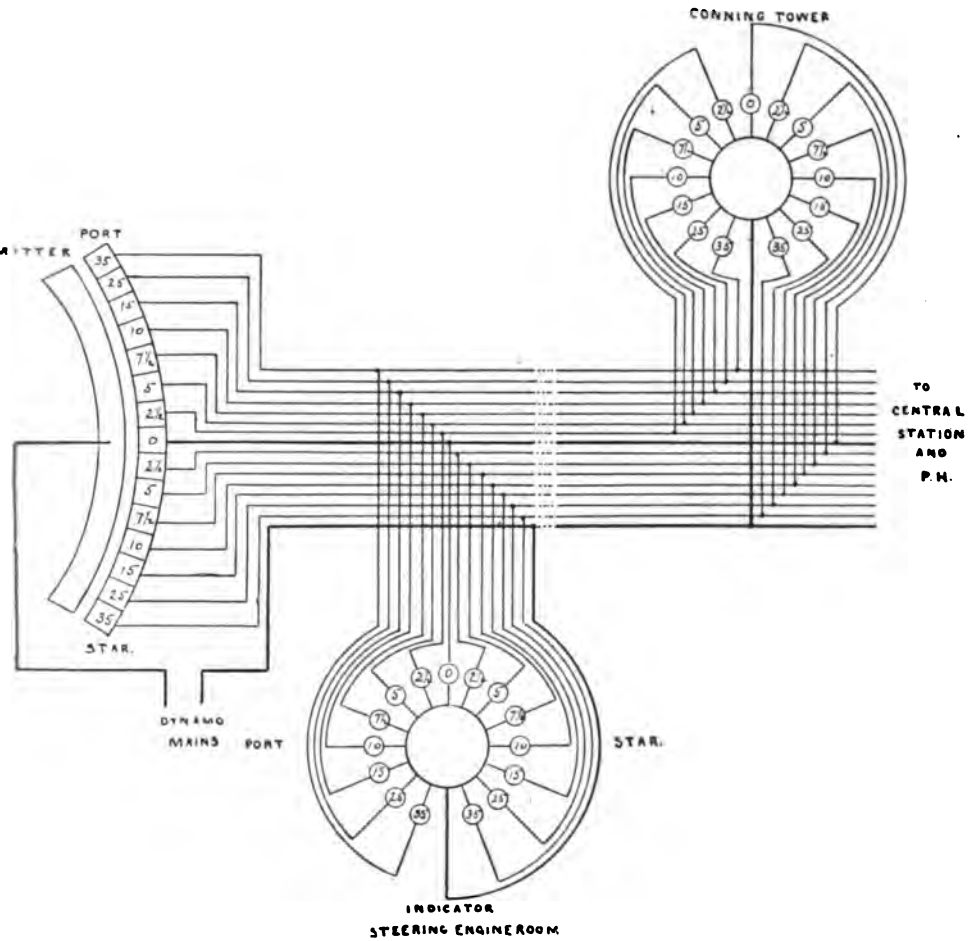


FIG. 371.—Wiring of Helm-Angle Indicators.

indicator showing the angle of helm by illuminating a number corresponding to that section.

The wiring is similar to that of engine and steering telegraphs.

Interior-communication cable is used, and wired with conduit and connection boxes.

The current is on the generator potential, being controlled by a properly-fused switch in central station or dynamo-room. All indicators are wired in multiple, as shown by Fig. 371.

Fire-Alarm Circuit.

The wiring of the fire-alarm or thermostat circuits is similar to that of annunciator circuits, one battery wire being led to all thermostats as a common return, a separate section wire running from the thermostat to the annunciator. When two or more thermostats are in the same compartment, they are wired in parallel.

The thermostats are placed in metal cases overhead in certain store-rooms and overhead and on bulkheads in coal bunkers. In some cases there is a separate circuit for fire alarms in magazines. These circuits are supplied by a battery of cells, twelve being usually sufficient. The annunciator is generally installed near the cabin, under care of the orderly, but later practice installs it in the dynamo-room.

Thermostats.—Thermostats are devices installed for the purpose of giving warning in case the temperature of the air in the neighborhood of their location rises above a certain degree. They are wired in open electrical circuits in such a manner that any increase of temperature above a specified amount acts to cause them to close the circuit which is connected with the alarm bell.

Two general types have been used, known as mercurial and mechanical types. The **mercurial type** consists of a metallic cup filled with mercury and sealed with a plug made of paraffin paper. Through the center of this plug passes a small glass tube similar to the tube of a thermometer, with its lower end flush with the mercury. A platinum wire passes through this tube and is secured to a brass plate on the insulating plug. The metallic cup forms one pole and the brass plate the other to which the circuit wires are secured.

As the temperature rises, the mercury expands from the cup up the tube, and at a certain temperature it makes contact with the platinum wire and closes the circuit through the annunciator and

rings the bell; at the same time dropping the shutter marked with its location. The thermostat is mounted in a water-tight box which is tapped for the conduit carrying the circuit wires. A hole in the bottom of the box exposes the metal cup of the thermostat.

The thermostat should be tested by the flame of an alcohol lamp, and this should be done with great care, as too much heat is liable to break it. Heat should be applied slowly, removing the lamp at intervals and taking it away entirely the instant the circuit is closed. There should be some arrangement of signals by which it is known the moment the bell rings on the annunciator. The cut-out switches on the annunciator should always be in circuit and in testing they can be cut out when the bell rings but should be closed when the test is over.

The **mechanical thermostat** depends on the expansion in length of a metal rod when it becomes heated. The active portion of the mechanical thermostat is a coiled spring, which, when heated with one end held fast, increases in length, and in so doing the free end turns.

The coil is a right-hand composite steel and brass spring of $7\frac{1}{2}$ turns, composed of steel inside, $\frac{3}{8}$ inch wide and .014 inch thick and brass outside .034 inch thick brazed together. As a protection from corrosion the springs are well tinned. The top of the spring is free and to it is secured a brass contact arm, and as the free end of the coil moves it carries this contact arm and with sufficient increase in length due to heat, the arm moves far enough to bring up against a terminal to which the leading wire to the annunciator is secured. The lower end of the spring is held fast by being screwed into a spindle which runs up through the inside of the coil and secured to the casting by which the thermostat is bolted in place. The other leading wire is secured to a terminal on the casting and the circuit is completed through the coil.

The terminal with which the bent arm on the free end of the spring makes contact is adjustable as to the distance the arm has to move to make contact by means of a set-screw and as the expansion depends on the temperature, this distance can be regulated for a given temperature.

Thermostats differ in type according to their location. For bunk-

ers the whole mechanism is enclosed in a water-tight case except sometimes when they are placed overhead when the spring may be protected by a perforated metal guard. For store-rooms the only protection necessary is that due to ordinary moisture and the greater area of the spring exposed to the heated air the better. The type for magazine is wholly enclosed so that the spark due to break of contact cannot come into direct contact with any inflammable gases that may be held in the magazine.

General-Alarm Circuit.

The general-alarm system consists of electromechanical, single-stroke gongs wired in multiple on a battery circuit and controlled by contact makers. The gongs are located in the living and working spaces so as to be heard by all the ship's crew. The contact makers are located in the chart house, conning tower and state-rooms of the captain and executive officer, and are placed apart from all push buttons to prevent their being accidentally put in action.

These gongs are partly electrical and partly mechanical in their action. Closing the circuit through one gong energizes an electro-magnet which attracts an armature, and the motion of this armature sets in operation a clockwork mechanism which sets a striker in reciprocating motion, striking the gong by a series of single strokes. The magnet coils of the gong are thoroughly insulated from the cores, and the winding consists of cotton-covered copper wire, which is run through insulating varnish as it is wound on. This is to avoid the grounds so often found in these coils. The mechanical part of the apparatus is usually located at the gong, but may be combined with the contact maker.

All the mechanism is inclosed in a composition-metal case, made water-tight by means of a sheet-rubber gasket. It has sufficient power to sound the gongs twice, two periods of not less than thirty seconds each, and after each action the mechanism returns automatically to its original state.

Each electromagnet requires a difference of potential at its terminals of 15 to 20 volts.

Contact Maker.—One form of contact maker used with these gongs consists of a brass water-tight box containing a hard-rubber

base on which are mounted section pieces separated from one another and to each of which is attached a section wire to each gong. Over these contact pieces slides a lever, pivoted at the center of the base, turned by a handle on the outside of the box, the common return wire to the battery connected to the lever at the center. From each gong is a common return to the battery. All the con-

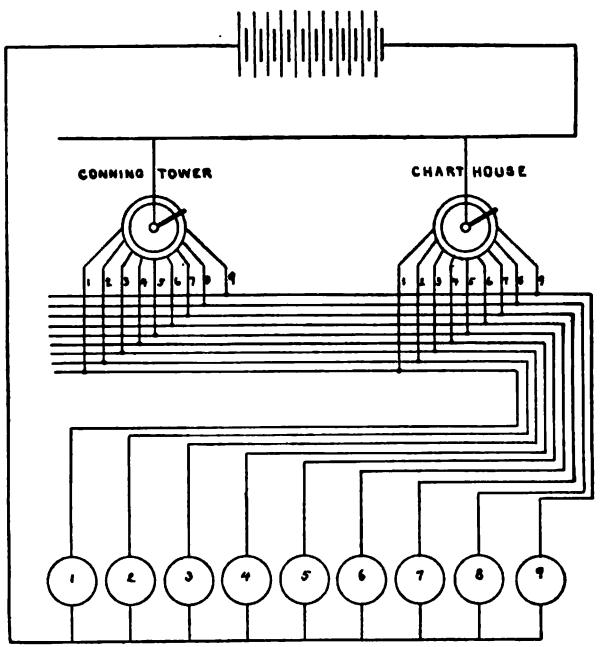


FIG. 372.—Wiring of General Alarm Gongs.

tact makers are connected in parallel by branching all the section wires and common return to each contact maker.

This system of wiring is shown in Fig. 352 and in Fig. 372. By this arrangement, as the contact lever is turned, successively making contact on each of the contact sections, the full battery current goes through each electromagnet. This system of wiring allows any single gong to be tested or rung from any contact switch and any fault to be easily found.

Another form of contact maker used with *single-stroke* gongs is similar to the above, but requiring continuous turning of the handle over the contact sections, each gong getting the full battery power once in each revolution, giving one stroke of the gong. In this form, the gong is a purely single-stroke one and requires no mechanical device at the gong, but only the electromagnet and armature which forms the striker.

To avoid turning the lever by hand, it is fitted with clockwork mechanism similar in its operation to that used with the "Warning Signals." The gear wheels of the mechanism are so proportioned that the contact maker makes about 20 revolutions for one turn of the operating handle, thus striking each one of the gongs about twenty times. The speed of the revolution of the contact maker is controlled so as to allow time for each gong to operate and continue the sounding of the alarm for about 30 seconds.

Care of Gongs.—In the electromechanical type, the armatures of the mechanism sometimes get out of adjustment, and this is remedied by releasing the escapement several times, setting the adjusting screws to suit. Care must be taken that the springs actuating the mechanism are not wound too tight.

Care must be taken that all contacts are kept clean and free from oxidation, and that in the rotary type of contact maker the tension on the contact spring is not too great, as too great friction between the switch and section points might cause the switch to stick, keeping the circuit closed through one of the gongs.

The battery should be frequently examined to see that it keeps up full voltage.

Warning Signals.

These consist of shrill whistles, operated electrically from the chart house and other places, according to the class of vessel. They constitute the signal for closing the water-tight doors. Where leads go through the protective deck, they pass through action cut-out switches.

The signal is required to be a succession of sharp, shrill whistles, audible above noise of running machinery, and differing in tone from any other whistle or signaling apparatus, so as to be instantly and unmistakably recognized under all conditions.

In its ordinary form, its action is partly electrical and partly mechanical and presents no unusual principles. When circuit is established by a contact maker at the place designated, usually the chart house, current flows around an electromagnet in the whistling apparatus, which, when energized, attracts an iron plunger into its core, this plunger pulling down with it an air-tight chamber on which is mounted the whistle. The air having no escape, is forced through the whistle, emitting a shrill sound. When the circuit is broken by the contact maker, the air cylinder is in its lowest position, and it is forced up again by two strong spiral springs to its former position. The circuit is again closed by the contact maker and the operation is repeated, the reciprocating action lasting about 35 seconds.

The **contact switch** consists of a set of clockwork gear mounted in a brass water-tight case and actuated by a lever on the outside of the box. Revolving the lever winds up a spring which sets the clockwork in motion and releases the lever, which falls back to its position by its own weight.

On one side of the contact lever are two carbons which, when raised by the lever, make contact through two other carbons, to each of which one end of the line wires are connected. Besides the carbon contacts, there are metallic contacts, the carbon ones taking the spark in breaking the circuit, but on account of their high resistance not giving enough current to the solenoid.

Great care is necessary in adjusting these contacts, allowing very little lead of the carbons, for otherwise the period of contact of the metal contacts is too short to allow of the reciprocation of the plunger of the solenoid.

The contacts in the contact maker should be kept clean and bright and the springs of the plunger should have proper attention. If the plunger cylinder is not kept clean or is allowed to rust, it will not work freely in the outer cylinder. Grounds will most likely be found in the coils of the magnet and they can be located by removing the fuses and testing with the magneto.

A typical circuit showing the method of wiring the controlling magnets is shown in Fig. 373.

In this wiring, connection boxes are on the main leads; branch

circuits taken to the whistles in parallel from the connection boxes. In some cases, two whistles are taken from the same branch, but there is usually but one. *W* represents the *whistles, CB* the *connection boxes, DM* the *generator mains* and *S* the *controlling switch,* usually located in the chart house.

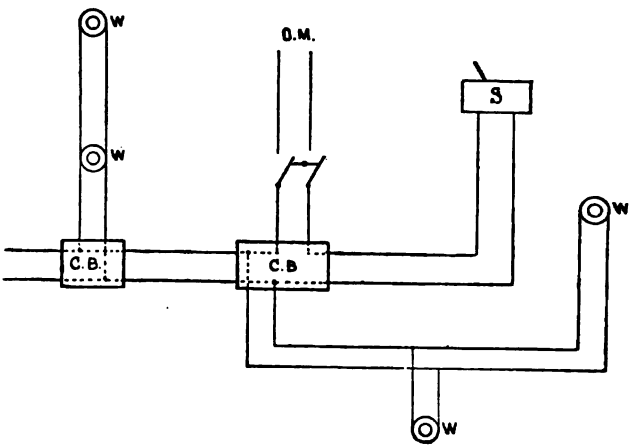


FIG. 373.—Wiring of Warning Signals.

Battle and Range-Order Circuits.

Battle and range-order instruments consist of combined transmitters and indicators for battle orders, for range orders, for powder-division or ammunition-hoist orders and of receivers for battle orders, for range orders and for powder-division orders.

These circuits are being replaced by the more modern fire-control circuits.

The **combined transmitter and indicator** for battle and range orders consist of a rectangular metal box, water-tight and fitted with water-tight cover screwed on a rubber gasket. It is mounted on a pedestal through which the wires enter. In this transmitter are mounted two rows of 5-candle-power lamps and a series of snap knife-edge switches, one in the circuit of each lamp. The lamps are covered by a series of circular pieces of transparent plates on which are marked the necessary battle or range orders. Surround-

ing each lamp is a metal tube, so all the light from one lamp will be thrown on its own plate and not illuminate any of the others.

The switches are arranged in two rows one above and one below the lamps, the switch handles projecting through the cover and are so arranged that when the switch handle is horizontal, the switch controlled by it is open, and when vertical the switch is closed.

The plates over the lamps are all contained in one piece which is secured by wing nuts and which may be readily removed, exposing the lamps.

The **receiver** for battle and range orders consists of a rectangular-shaped metal water-tight case with hinged cover made water-tight by butterfly-winged nuts pressing it against a soft-rubber gasket. It is made to be secured against a bulkhead, the wires entering at the bottom through stuffing tubes. Inside the case are mounted four rows of lamps. The hinged cover is similar to that in the transmitter except that it is the same size as the receiver case, and has circular transparent discs with the orders marked on them corresponding to those in the transmitter. The lamps are fitted with shades as in the transmitters.

Wiring.—In the transmitter one terminal of each switch is connected to a common bus bar which forms a terminal for one of the generator wires, and the other terminal is connected to its section wire leading to its lamp. When the switch is turned the section wire is connected to the common return wire through the switch.

In the receiver one terminal of each lamp is connected to a bus bar to which the common feed wire is connected. The other terminals are connected to the section wires leading to the switches in the transmitter.

To transmit an order it is simply necessary to turn the switch in the transmitter for the lamp under the desired order, when that lamp in both the transmitter and receiver will be lighted. The wires used with these instruments are made up in cables, the section wires being formed around a central wire which forms the common return. The main feeders are protected by fuses of such capacity to allow generally four lamps in each transmitter and receiver to be lighted.

If grounds appear, they will be indicated on the ground detector

on the main switchboard, and to locate grounds on any section wire, all the lamps in all receivers should be removed and each section tested separately.

Powder-Division Circuit.

The transmitter and receiver for this circuit are essentially the same as those for battle-order circuits and the wiring is on the same principle. The transmitter has one row of six lamps and one row of six switches mounted in a water-tight case on a pedestal, while the receiver has two rows of lamps of three each in a water-tight case designed to secure against a bulkhead.

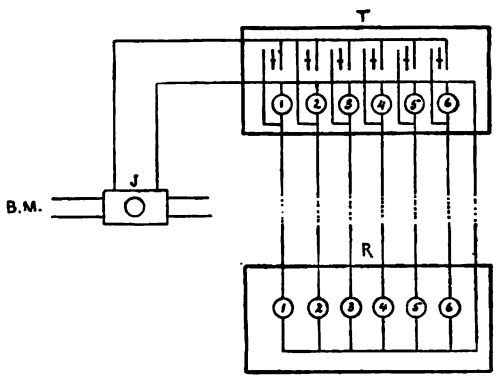


FIG. 374.—Wiring of Powder-Division Circuit.

The wiring for a typical powder-division circuit is shown in Fig. 374, when *T* represents the transmitter, *R* the receiver, *BM* the battle mains and *J* a junction box.

Fig. 375 represents the wiring of a typical circuit for battle or range orders. Current is taken from a battle main of the generator potential through a junction box to the transmitter where all the lights in the transmitter and in all indicators are controlled by switches. The wires from the transmitter to the different indicators are made up in one cable, that for the battle order consisting of one insulated stranded conductor of 38,912 circular mils surrounded by 25 insulated conductors, each consisting of a single strand. The cable for range-order instruments consists of an insu-

lated stranded conductor of 22,799 circular mils surrounded by 18 insulated conductors, each consisting of a single strand.

The cables may be led into connection boxes from which branches to separate indicators may be taken as shown in Fig. 375. *T* represents the transmitter with switches *S*, *R* the receivers, *CB* a connection box, *BM* the battle mains and *J* a junction box. The cables are shown made up at *C*.

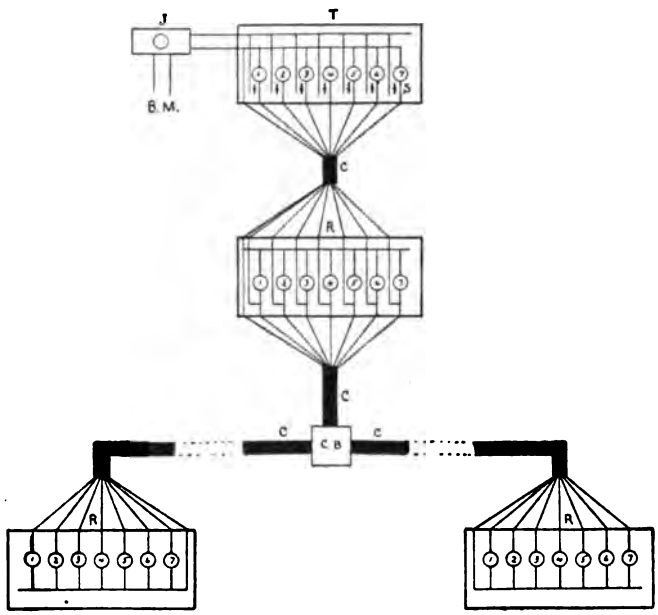


FIG. 375.—Wiring of Range-Order Circuits.

Fire-Control Circuits.

The different electrical circuits under the present system of fire control are embraced under the following heads:

1. **Fire-control telephone system.**
2. **Range and deflection circuits.**
3. **Salvo-firing circuits.**
4. **Broadside ammunition-hoist signals.**
5. **Cease-firing circuits.**

Fire-Control Telephone System.

The object of this system of fire control is to afford direct communication from the different fire-control stations to the class of guns controlled from each station with intercommunication between certain of these stations. In general, there are two stations for the control of the 12-inch turret guns, one on each mast in a specially-constructed crow's nest. A short distance below these, or in the upper tops, are the stations for the control of the 8-inch turret guns. Other control stations are those for the broadside guns, both forward and aft on the starboard side and forward and aft on the port side; and for torpedo defense, both starboard and port, forward, and starboard and port, aft.

In order to properly divide up the circuits with as little confusion as possible and that communication be rapid and direct, a series of sub-stations are provided with operators in each for the proper manipulation of the switches to put the desired stations in communication with each other, and for passing the word received from the fire-control stations to the divisional officers and gun-pointers.

The following table shows the general distribution and installation of telephones in a modern vessel. At each one of the stations designated by a serial number there is installed some form of a head set of telephone instruments, including double receivers and a transmitter:

TELEPHONE STATIONS.

Circuit No.	Serial No.	Location and leads from	To	Serial No.
1	1	Captain's battle station.	For'd 12" F. C. S.	3
1	2	Central station No. 1.	After 12" "	4
		Telephones 1 or 2 connects with	Star. for'd torp. def. F. C. S.	5
		3-4-5-6-7-8 or 9 by means of a transfer switch in panel in central station No. 1, and are connected to the same circuit.	Port " " " "	6
			Star. after " " "	7
			Port " " " "	8
			After torp. firing station.	9
2	10	For'd 12" F. C. S.	Sub-station No. 1, Range.	11
		Telephones 10-11-12-13 are all connected in parallel on the same circuit.	" " Deflec.	12
			" " B.o.	13
3	14	After 12" F. C. S.	Sub-station No. 2, Range.	15
		Telephones 14-15 16-17 are all connected in parallel on the same circuit.	" " Deflec.	16
			" " B.o.	17

TELEPHONE STATIONS.—*Continued.*

Circuit No.	Serial No.	Location and leads from	To	Serial No.
4	18	Sub-station No. 1. By means of transfer switches on panel in sub-stations 1 and 2, telephones 18 and 19-20-21-22-23 are connected in parallel on circuit 4 or telephones 18 and 25-26-27 28-29 are connected in parallel on the same circuit.	For'd 12″ turret right sight-setter.	19
			" " " left " "	20
			" " " trainer.	21
			" " " Turret Off. right.	22
			" " " " " left.	23
5	24	Sub-station No. 2. By means of transfer switches in sub-stations 1 and 2, telephones 24 and 19 20-21-22-23, and 24 and 25 26-27 28-29 are connected in parallel on circuit No. 5. Both turret guns can be controlled from either sub-stations 1 or 2.	After 12″ turret right sight-setter.	25
			" " " left " "	26
			" " " trainer.	27
			" " " Turret Off. right.	28
			" " " " " left.	29
6	30	For'd 8″ F. C. S., star.	Sub-station No. 3, Range.	32
	31	After 8″ " "	" " Deflec.	33
		Telephones 30 or 31 are connected to 32-33-34 by a transfer switch in sub-station No. 3.	" " B.o.	34
7	35	For'd 8″ F. C. S., port.	Sub-station No. 4, Range.	37
	36	After 8″ " "	" " Deflec.	38
		Telephones 35 or 36 are connected to 37-38-39 by a transfer switch in sub-station No. 4.	" " B.o.	39
8	40	Sub-station No. 3. The group of telephones in each 8″ turret is connected to a double-pole double-throw transfer switch in sub-station No. 3, and by properly closing these switches telephone 40 can connect with all the telephones in any one group, or with all the telephones in all four groups.	For'd 8″ turret right sight-setter.	41
			" " " left " "	42
			" " " Turret Off. right.	43
			" " " " " left.	44
			After 8″ turret right sight-setter.	45
			" " " left " "	46
			" " " Turret Off. right.	47
			" " " " " left.	48
			Star. 8″ turret right sight-setter.	49
			" " " left " "	50
			" " " trainer.	51
			" " " Turret Off. right.	52
			" " " " " left.	53
			Port 8″ turret right sight-setter.	54
			" " " left " "	55
			" " " trainer.	56
			" " " Turret Off. right.	57
			" " " " " left.	58
9	59	Sub-station No. 4. By the transfer switches in this station, telephone 59 can connect with all telephones with which No. 40 can connect.		
10	60	For'd 6″ F. C. S., star.	Sub-station No. 5, Range.	62
	61	After 6″ " "	" " Deflec.	63
		Telephones 60 or 61 connect with 62 63 64 by a transfer switch in panel in sub-station No. 5.	" " B.o.	64
11	65	For'd 6″ F. C. S., port.	Sub-station No. 6, Range.	67
	66	After 6″ " "	" " Deflec.	68
		Telephones 65 or 66 connect with 67-58-69 by a transfer switch in sub-station No. 6.	" " B.o.	69

TELEPHONE STATIONS.—*Continued.*

Circuit No.	Serial No.	Location and leads from	To	Serial No.
12	70	Sub-station No. 5. By transfer switches in sub-station No. 5, telephone 70 can be connected to 71-72 or 73-74-75-76-77-78 or to all of them in parallel.	Star. broadside gun No. 1 " " " No. 3 " " " No. 5 " " " No. 7 " " " No. 9 " " " No. 11 " " Div. Off. for'd. " " " " aft.	71 72 73 74 75 76 77 78
13	79	Sub-station No. 6. By transfer switches in sub-station No. 6, telephone 79 can be connected to 80-81 or 82-83-84-85-86-87 or to all of them in parallel.	Port broadside gun No. 2 " " " No. 4 " " " No. 6 " " " No. 8 " " " No. 10 " " " No. 12 " " Div. Off. for'd. " " " " aft.	80 81 82 83 84 85 86 87
14	88	Torpedo F. C. S., star. for'd. By transfer switch in sub-station No. 5, telephone 88 can be connected with telephones 71-72-77.	Star. secondary gun No. 1 " " " No. 3 " " " No. 5	89 90 91
15	92	Torpedo F. C. S., port for'd. By transfer switch in sub-station No. 6, telephone 92 can be connected with telephones 80-81-86.	Port secondary gun No. 2 " " " No. 4 " " " No. 6	93 94 95
16	96	Torpedo F. C. S., star. aft. By transfer switch in sub-station No. 5, telephone 96 can be connected with telephones 73-74-75-76-78.	Star. secondary gun No. 7 " " " No. 9 " " " No. 11	97 98 99
17	100	Torpedo F. C. S., port aft. By transfer switch in sub-station No. 6, telephone 100 can be connected with telephones 82-83-84-85-87.	Port secondary gun No. 8 " " " No. 10 " " " No. 12	101 102 103
18	104	For'd F. C. S. This circuit leads direct from main switch panel.	After F. C. S. Torpedo firing station star. for'd. " " " port " " " " aft.	105 106 107 108
19	109	After torpedo-firing station. This circuit leads direct from main switchboard.	Torpedo firing station star. for'd. " " " port " For'd torpedo-room. After " "	110 111 112 113
20	114 115	Captain's battle station. Central station No. 1. By a transfer switch in central station No. 1, either telephone 114 or 115 can be connected to 116-117-118. Telephone 114 is portable, and can be plugged in a receptacle in the battle station or on the bridge.	Star. engine-room. Port engine-room Steering engine-room.	116 117 118

Fire-Control Telephone-Circuit Switchboard.—In the preceding table the telephone instruments at the different stations are shown as grouped on twenty circuits. · These circuits lead to the numbered circuit switches shown on the switchboard in Fig. 376. This switchboard is located near the sub-stations which are grouped

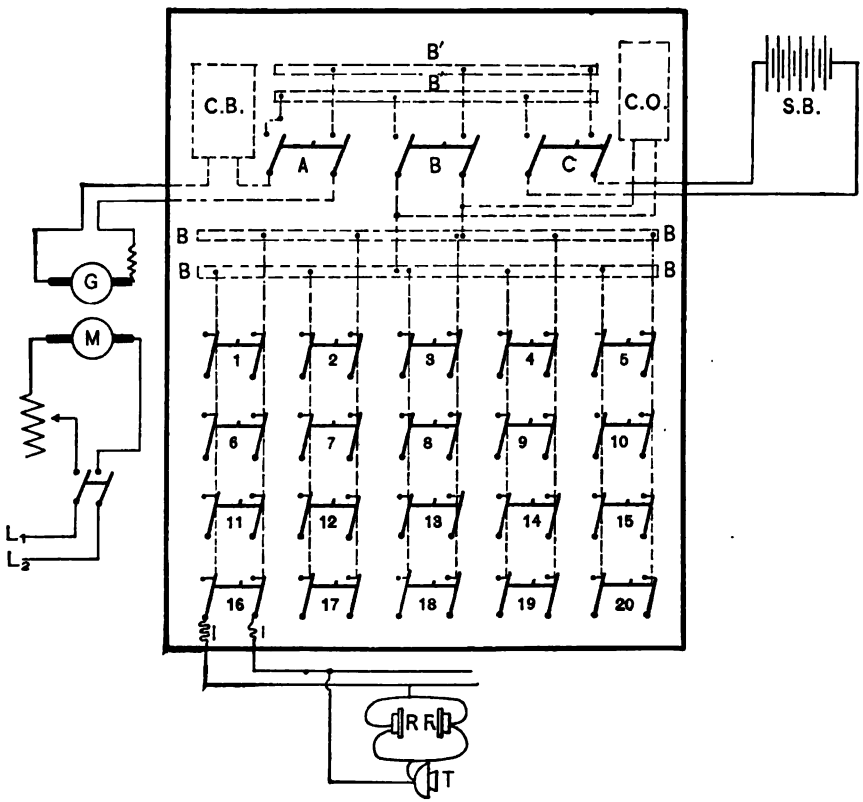


FIG. 376.—Fire-Control Telephone-Circuit Switchboard.

together as far as possible on a lower deck and near central station No. 1. This switchboard is furnished with current from a motor generator, shown on the left or from a storage battery *SB*, shown on the right. The leads L_1 and L_2 are taken from a switch on the interior-communication switchboard located in central station

No. 1. To use current from the motor generator, switches *A* and and *B* are closed, which energizes the bus bars *BB* to which are connected all the circuit switches. The storage battery can be used by closing switches *B* and *C*. The circuits lead to panels in the different sub-stations and the current for the instruments at the different stations is finally distributed from these points. The head set shown at the bottom illustrates how the instruments are taken off in parallel at the different stations.

Each circuit is provided with an impedance coil, shown at *II* in the circuit shown leading from the board. The lead from the motor generator has inserted in it a reversible circuit breaker *CB* and in parallel with the leads from the main switch *B* is a condenser *CO*. By closing the switches *A* and *C*, the storage battery may be charged from the motor generator.

Telephone Circuits.—The general arrangement of the various circuits is illustrated in Fig. 377. This shows two sub-station, *SS* No. 1 and *SS* No. 2, which, in this case, are in one compartment. In this compartment is a transfer switch panel containing the switches 1 and 2. This circuit shows the means of communicating from the 12-inch control stations to the 12-inch turret guns. 10 is the forward control station and 14 is the after station; the group of telephones 19, 20, 21, 22 and 23 are in the forward turret and 25, 26, 27, 28 and 29 are in the after turret. The circuits 2, 3, 4 and 5 at the bottom lead to the corresponding numbered switches on the fire-control switchboard.

When No. 2 circuit switch is closed on the switchboard, it will be seen that No. 10 is in communication with 11, 12 and 13. There is an operator at each one of these telephones with the head receivers in place. The range, deflection and any battle orders are communicated over the same line, and operator at 11 takes the range, 12 the deflection and 13 the general orders. These orders are communicated to the operator at 18 who makes the connections and passes the word given to him. If No. 10 gives instructions to the forward turret, the operator closes switch 2 up, which puts his phone in connection with all the phones in the forward turret. When he passes the word the sight-setters at 19, 20 and 21 get it and set the sights accordingly.

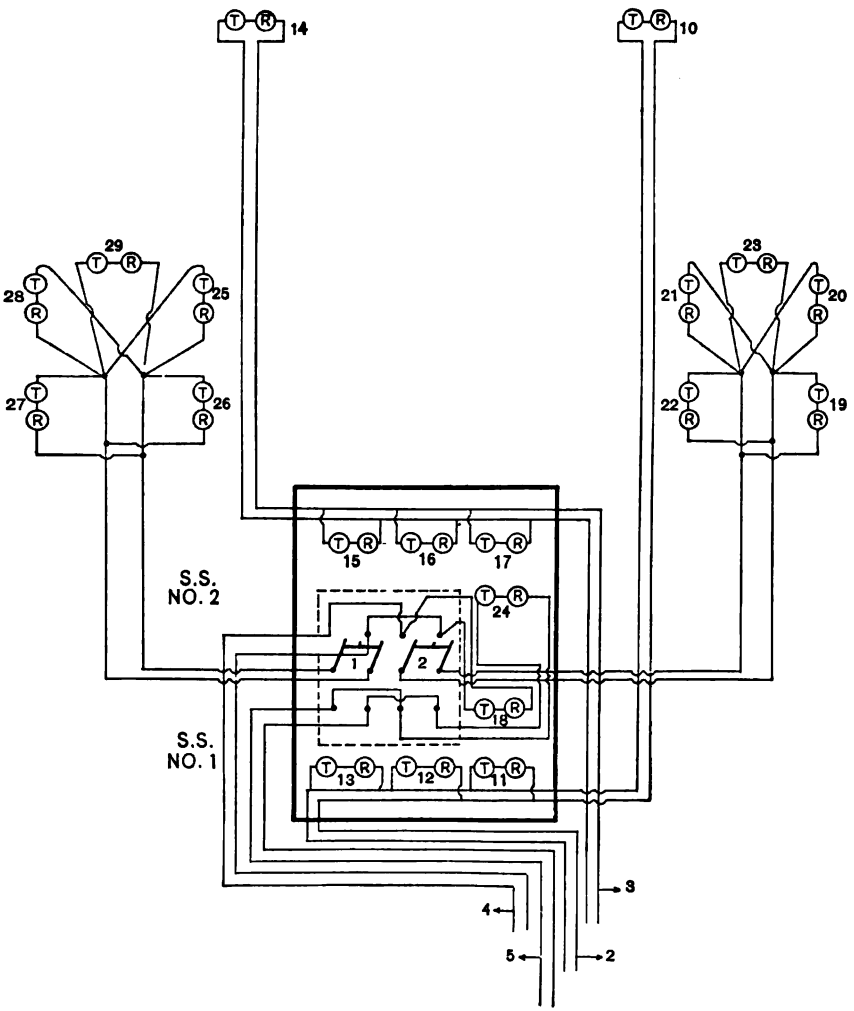


FIG. 377.—Telephone Circuits to 12″ Turrets.

If the after turret guns are to be controlled from the forward station, switch 1 is closed up, when 18 can pass the word to both turrets at the same time or only one, depending on which of the switches 1 and 2 are closed.

If the forward turret is to be controlled from the after station, 15, 16 and 17 get the word, and it is passed by an operator at 24 who closes switch 2 down, when he is in communication on current from circuit 5. To communicate with the after turret from the after control station, switch 1 is closed down.

Either control station can thus communicate with either turret or both at the same time, or one station can communicate with one turret, while the other can communicate with the other.

Stowage Boxes.—All telephones except those in the sub-stations when not in use are kept stowed in water-tight boxes secured permanently at places conveniently near where they are to be used. The transmitters and receivers are connected to terminals in these boxes by flexible conductors so they may be adjusted in place on the head and the operator free to move around. For the phones for divisional officers, receptacles are installed at suitable places, where the phones may be plugged in.

For use in all sub-stations and the captain's battle station, a commercial form of head set combining both the transmitter and receivers are used, and at control stations and gun stations, the standard head set specially made and previously described.

Range and Deflection Circuits.

In addition to the telephone circuits from the various fire-control and sub-stations to the different turrets and guns, there are installed wiring circuits for actuating electrical devices which give visual signals for sight-bar range and deflection. In general these devices consist of a transmitter and an indicator, the one for transmitting the desired signals, the other for indicating them. It is usual to use combined range and deflection transmitters, but separate indicators for the range and deflection.

A general scheme of installation is as follows: In one of the sub-stations connected by telephone circuit to the forward 12-inch turret is a combined range and deflection transmitter connected to

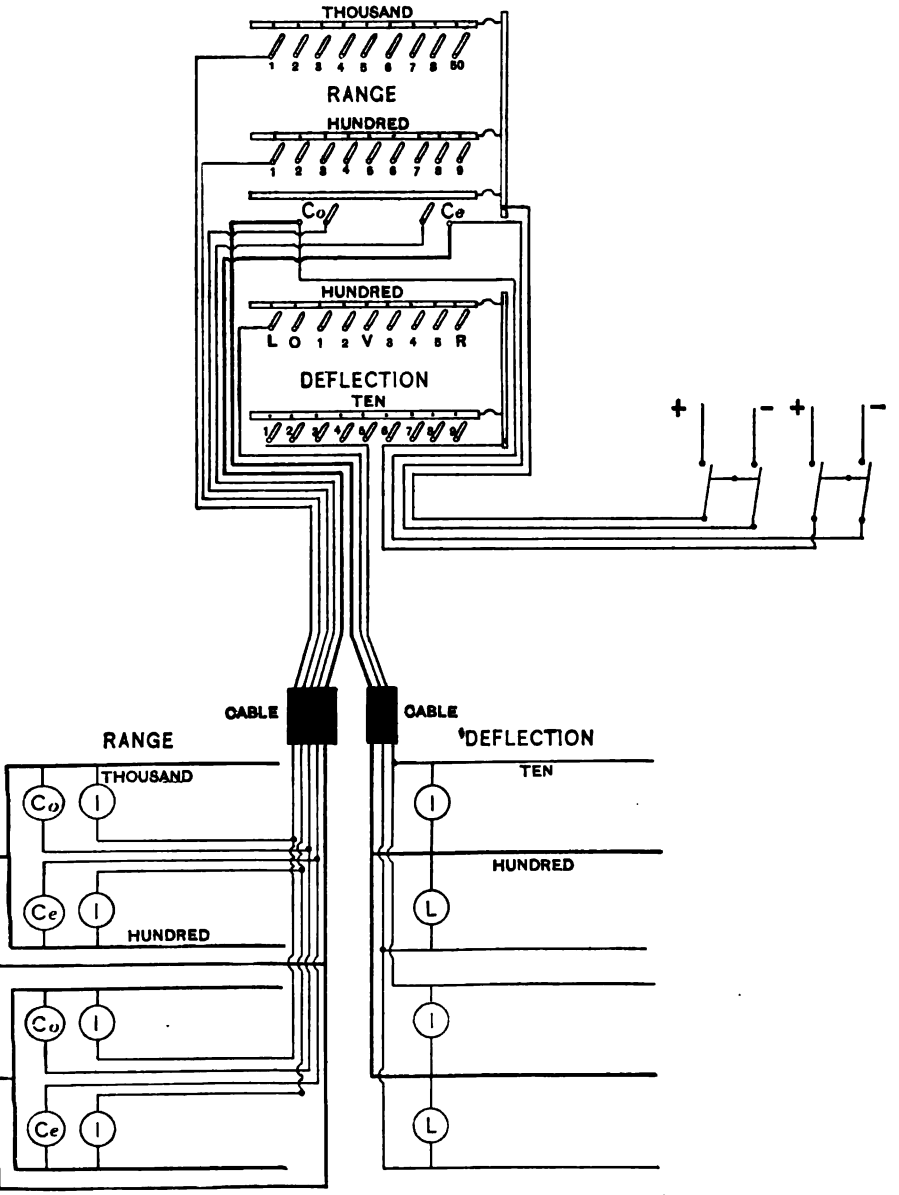


FIG. 378.—Wiring-Diagram of Range and Deflection Circuits.

indicators in the turret, with one range and one deflection indicator for each gun. A similar equipment gives signals to the after 12-inch turret from the sub-station, with which it has telephone connection. In the sub-station from which the 8-inch turrets are controlled by telephone circuits is a combined range and deflection transmitter with range indicators and deflection indicators in each 8-inch turret for each gun. In the sub-station controlling the starboard broadside guns is a separate range transmitter with range indicators at each gun and a separate deflection transmitter with deflection indicators at each gun. In another sub-station and at the guns of the port broadside battery there are similar devices.

A wiring diagram showing the connection of the transmitters and indicators is shown in Fig. 378.

The upper figure represents a combined range and deflection transmitter and consists of five horizontal bus bars, connected through fuses to two vertical bars. The numbered switches are single pole and connect the wires leading to the indicators to the source of current. Each switch completes the circuit through a glow lamp in an indicator, which, when lit, illuminates a dial painted with a number corresponding to that of the switch. Current is taken from a separate panel board which in turn receives current from the interior-communication switchboard in central station No. 1. The switches on the right indicate those on the range and deflection switch panel. The left one controls the current to the range bus bars and to the center bus bar which connects through switches to lamps on the range indicator showing "Commence" and "Cease," *Co* and *Ce*. The right-hand switch controls the current to the deflection bus bars.

It will be noticed that the common negative wire simply passes through the transmitter but there is a wire for each separate switch. These wires are made up in cables and lead to the indicators where they are connected to their appropriate lamps. Only the wires for the commence and cease lamps and one from each bus bar are shown, so the connections are easily traced. As many indicators as may be desired can be wired in parallel, and in the circuit for the 8-inch turrets, there would be eight range indicators and eight deflection indicators all wired in parallel from the same wires from

the transmitter, and closing one switch on the transmitter lights a lamp in each of the eight indicators.

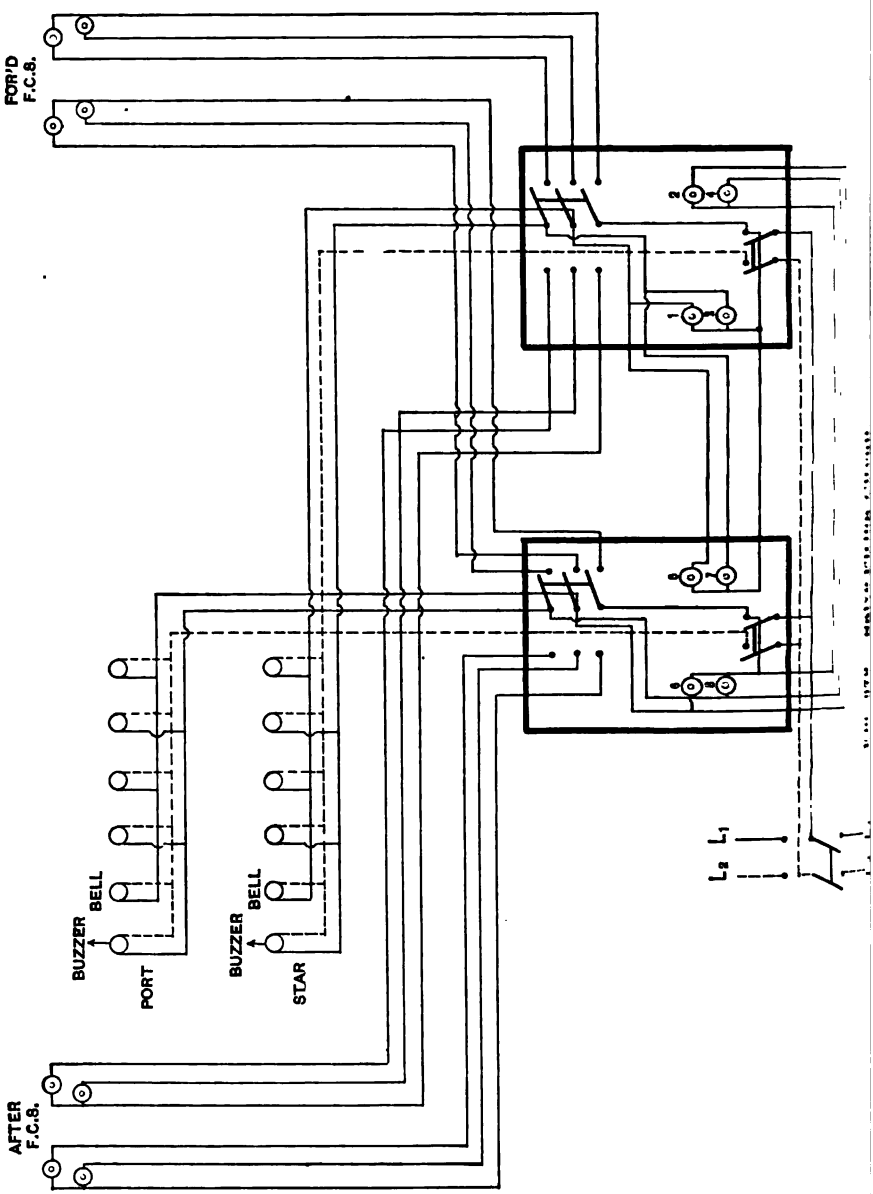
The method of signaling is apparent. If the operator in the sub-station gets word from the fire-control station that the range is 8650 yards, it is only necessary to close switches 8 in the thousand (upper) row, 6 in the hundred (lower) row and 50 in the upper row of the range bus bars when a corresponding display will be made in each range indicator by the lamps 8 in the thousand row, 6 in the hundred row and 50 in the thousand row being lighted. Similarly any correction for deflection is shown by closing appropriate switches in the lower two bus bars.

The separate range and deflection transmitters are entirely similar to the combined one, but each has only two bus bars and two rows of switches. The bus bars are energized by the leads from the switch panel from one side of the switch, the common negative simply passing through the instrument to the indicators.

Salvo-Firing Circuits.

The salvo-firing circuit is wired for the purpose of giving signals at the broadside guns, so that all may be fired simultaneously. Near each gun is installed a vibrating bell which is operated to indicate a "stand-by" signal, and secured to the person of the gun-pointer is a buzzer which, when the operating circuit is closed, gives the signal to fire.

A wiring circuit is shown in Fig. 379. There are two panels installed in sub-stations of the fire-control system, from each of which are run wires to both of the main fire-control stations. The positive mains to which the bells and buzzers are connected in parallel run from the hinge side of a double-pole, double-throw switch, and the negative main runs direct from the main switch on the panel. Throwing these double-throw switches one way or another connects either the forward or after fire-control stations to the bell and buzzer leads. By this means, the bell or buzzer signal can be given from either fire-control station to either the starboard or port battery or both, but not from both stations at the same time. In the figure, when the double-throw switches are thrown to the right, the circuits to both broadside batteries are connected to the forward


FOR'D F.C.S.
AFTER F.C.S.
BUZZER
BELL
PORT
BUZZER
BELL
STAR
L2
L1

control station, and when to the left, to the after control station. One battery may be controlled from the forward station, and the other from the after station by properly throwing the switches on the panels.

By an arrangement of the numbered push buttons on the panels either battery may be controlled from each panel at all times. As shown, the upper row of push buttons controls the bells and the lower row the buzzers. Buttons marked 1, 3, 5 and 7 control the starboard battery and 2, 4, 6 and 8 the port battery.

The panel main switches are connected in parallel with the leads from a double-pole, double-throw switch, which can be connected to either the leads from a battery L_1L_2 or from a dynamotor $L'_1L'_2$.

As actually installed, the buttons 2 and 4 control the starboard battery and 1 and 3 the port, so that everything connected with the starboard guns is on the right-hand side and with the port guns on the left-hand side.

The wires leading to the fire-control stations terminate in a stowage box, from which flexible conductors are lead to pear-shaped push buttons with two pushes. The push for the bells is on the end and that for the buzzers is on the side of the pear push. Each push is marked with the name of the battery it controls. When not in use the pear pushes are hung in the water-tight stowage box.

Ammunition-Hoist Signals.

Ammunition-hoist signals are installed as a means of communication between the broadside guns and the lower decks or passages from which the ammunition is supplied. In general there is installed one complete outfit of signals for each ammunition hoist. Each outfit consists of two indicators and a switch box, one indicator and the switch box being at the top of the hoist, the other indicator at the bottom.

The indicators are entirely alike and each consists of a composition water-tight box in which are mounted five incandescent 5-candle-power lamps. These lamps are surrounded by cylindrical casings so arranged that the light from each is only given out in one direction, towards the cover of the containing box, which has circu-

lar openings cut in it covered by translucent discs. On these discs are painted the general battle orders, Hoist, Lower, Stop, Com. Shell, A. P. Shell.

The switch box is a standard 8-way distribution box, with a modified cover and with interior fittings for five standard 5-ampere

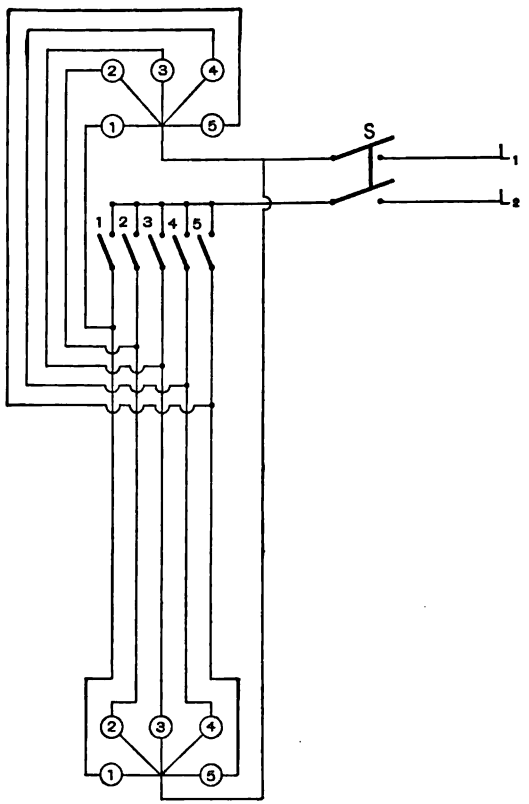


FIG. 380.—Wiring Diagram. Ammunition-Hoist Signals.

switches whose switch handles are mounted on the outside of the cover. Each one of these switches control two lamps, one in each indicator, and the disc covers of these lamps have the same marking.

The wiring plan is shown in Fig. 380. The leads L_1L_2 are run in conduit from the ship's lighting mains into a standard 25-

ampere switch S, from which the conduit is run to the switch box. To operate, it is only necessary to turn the switch at the top of the hoist which results in lighting the two lamps, one at the top of the hoist and one at the bottom. These lamps illuminate the discs marked with the order it is desired to communicate to the ammunition passers below. Each switch is marked with a name plate with the same legend as that on the lamps that it controls.

Cease-Firing Circuits.

Cease-firing gongs are installed for the purpose of giving a general signal for "cease firing." It is usual to so wire them that they can be controlled but from two places, the captain's battle station and in the main central station, which in modern ships is fitted as a battle station.

The gongs are 6-inch vibrating gongs and with the electromagnets wound for the voltage of the ship's mains. They are mounted in each of the principal fire-control stations, forward and aft, on the flying and upper bridges, on the upper deck for the secondary battery, along the main deck for the broadside battery, in all 8-inch turrets and in 12-inch turrets.

The general wiring plan is shown in Fig. 381. The mains L_1 and L_2 are taken from a switch on the interior-communication switchboard and lead to a transfer switch on one of the telephone switch panels, from which wires are run to a connection box and then to a feeder junction box in the captain's battle station. The switch TS may be used to direct the current to either the contact maker, switch S, in the captain's battle station, or to the switch S' in the central station No. 1. From the connection box the wires are run in conduit to the different points of installation of the bells, the circuit resembling an ordinary simple parallel lighting circuit, in which all branches to gongs are taken from fused junction boxes. All the gongs are wired in parallel and all are sounded together by the operation of closing the switch S, if TS is closed up, or switch S', if TS is closed down.

Circuit Switch Panels.

All telephone circuits are taken from the switchboard located in a place convenient to the sub-stations. The ordinary system re-

quires about twenty circuits which lead from the main switchboard to circuit panels in the different sub-stations where they are controlled by switches manipulated by the different operators.

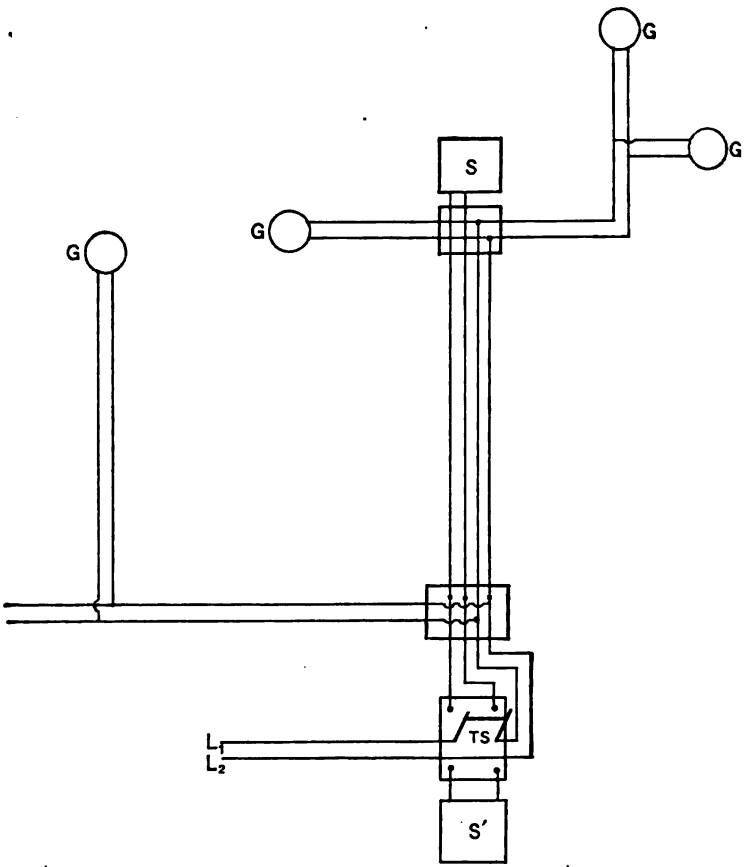


FIG. 381.—Wiring Diagram of Cease-Firing Gongs.

The generation and distribution of current for the talking circuits of the telephones up to the point of leaving the switch panel is shown in Fig. 376. There are no calling circuits and the system is complete only when each telephone has its own operator.

Wiring Appliances.

The wires for all electrical means of interior communication are run in conduit or molding and the same appliances are used with these to insure thorough water-tightness through bulkheads or decks as are described under wiring appliances for power or lighting circuits. These include different forms of stuffing tubes, junction boxes and the like. In addition there are a few appliances used only on this system. They include besides those already described cut-out switches, connection boxes and the different forms of push buttons.

Cut-Out Switches.—These are used to cut out of circuit such circuits that are used in ordinary times and which are wired with circuits that should be used in times of action. The idea is to cut out such exposed circuits not needed in action to prevent injury to them from interfering with the needed action circuits.

A cut-out switch consists of a metal box fitted with water-tight stuffing glands through which the cables or wires enter the box. The interior of the box is fitted with a number of flat spring contacts to which the wires are connected, the springs overlapping one another in the center of the box on one side of a switch shaft. This shaft is faced on two sides with hard rubber, and when the shaft is turned so that one of the hard-rubber sides forces the spring contacts together, circuit is made through the box.

The boxes are made in three sizes, for 8 wires, 15 wires and 20 wires. The boxes are fitted with bosses taped for conduit, according to the most desirable lead for the wires. It is sometimes desirable to lead the wires through the bottom of the box, in which case a box tube is used with gland on the outside of box. The latest form requires the cover for the box to be of sheet brass with nipple and cap the same as used for feeder and junction boxes.

The handle for operating switch in this type projects through the cover and acts as a "stop" to limit the throw of the switch, by striking against the inner side of the nipple. When the handle is up against the top part of the nipple, the switch is off and when down against the lower part of the nipple, the switch is on.

Another type of a cut-out switch consists of a metal box with

bosses which may be tapped to receive the conduit in which the wires are run. The top of the box is provided with two hinged doors which ordinarily are screwed down on rubber gaskets to make it water-tight. To open the doors it is necessary to take out the screws when the doors may be opened on their hinges.

In the interior is a long row of terminal contacts to which the incoming wires are soldered, and each contact is secured to the clip side of the single-blade switch. There is a switch blade for each wire, and the circuit is continued through the switch to the hinge side where terminal pieces are soldered to the outgoing wires. All the switches in each box may be operated at once by one handle, though on account of the great number it is usual to divide the switches among two handles.

The switch handles are of such size and shape that they may be closed or opened and the doors then shut.

Connection Boxes.—These are used to break the leads of wires to take off branches and to obviate the necessity of soldering or making joints. They consist of water-tight metal boxes fitted with covers set up by wing nuts against rubber washers or with a cap secured by countersunk screws. When used with conduit it is tapped into the box and made water-tight by a gland and stuffing tube in the pipe near the box. When cables from molding lead into a box, standard stuffing tubes are used to make it water-tight.

In the connection box, each wire of the cable has a flat copper terminal soldered on, on which is stamped the serial number and letter of the circuit to which it belongs. The terminals are then connected together on a metal lug secured to a porcelain base, the terminals set up by screws. In one form of box, the porcelain base is not used, the wires being spliced together and insulated.

Push Buttons.—These are of two classes, water-tight and non-water-tight. The *water-tight* type is enclosed in a cast-brass case, made water-tight against a soft-rubber washer. The contact springs are platinum-tipped and are mounted on an insulating plate. The *non-water-tight* type is similar except it is not made water-tight, and is fitted with a push of hard black rubber.

Pear buttons are fitted in quarters and offices with flexible cord. They are all non-water-tight. They are single, double or treble

pushes made of black hard rubber, pear-shaped. The pushes are of metal heavily nickeled, contacts made by circular pieces of nickel-plated metal held away from the contact screws by small spiral springs. All contact points are platinum-tipped.

Interior-Communication Switchboard.

It is usual to install all the batteries for the interior communication in one place, usually the dynamo-room or central station. The batteries for voice-tube calls, telephone calls and those for operating fire alarms and alarm gongs are grouped on trays in a locker, the trays containing not more than 12 cells each, each cell in a separate compartment in the tray and the trays separated by partitions. Each tray is fitted with handles and with bolts for securing in place and with a name plate indicating the circuit which is supplied by the battery in the tray.

The battery terminals are connected to a switchboard from which the battery wires lead out to their various circuits. Telegraph and indicator circuits as well as those for battle-order and range-order circuits are connected with the generator and the current for them is distributed from a common switchboard with the battery circuits. In this way arrangement is made by which the battery circuits can be fed from the generators in case the batteries run down. This requires the introduction of a resistance to cut down the generator potential to that needed on the battery circuits.

Rotary Transformer.—If a resistance in circuit is not used, a transformer is employed. This is of the rotary type, usually fitted with one armature with two windings and two commutators, one winding receiving the generator voltage, the armature revolving as a motor, which, owing to its second winding, delivers current through the second commutator at a reduced voltage which can be used on the battery circuits. (See under Dynamotor, Chapter XX.)

CHAPTER XXXV.

CARE OF ELECTRIC PLANT AND ACCESSORIES.

The first requisite in the care of all electric machinery is cleanliness, and this refers not only to the generators and engines under one's care, but to all parts of the electric installation. The general appearance of a dynamo room and its appurtenances will be an index to the care given to the machines themselves. It is usually found that the engines of generating sets are a source of more trouble than the generators, mechanical faults being more persistent and more apt to occur than electrical ones, and a good dynamo tender should be above all a good engineer, at least as far as his particular engine goes. Instructions are now furnished with generating sets showing details of the moving parts and how to assemble and disassemble them, and it remains with those in charge to see that these are faithfully and carefully followed.

After Stopping.

After a machine is shut down after its usual run, it should at once be gotten ready for starting again, and all parts thoroughly cleaned and inspected. If not of the self-oiling type, all oil feeders should be turned off, the reservoirs filled and the cups themselves cleaned and the glasses polished. All oil about the engine, especially in the crank pits and in the foundation, should be wiped up with waste, and the parts dried and cleaned, the oily, dirty waste being immediately gotten rid of and not left in corners or out-of-the-way places. All moving parts should be wiped off, all bearings examined, and all stuffing-boxes looked at, and if there has been evidence of leaking during the run, they should be properly set up. The metallic packing should be removed at times and examined for wear, as should also the shaft bearings for an examination of the babbitting. All grit, dust and dirt of every kind should be carefully wiped off, being careful to see also that there are no stray pieces

of waste left sticking to any part, whether moving or stationary. It is better for this purpose to use cotton rags in preference to waste.

If the engine is stopped with a throttle, the engine stop valve should be closed and also the exhaust valve, the drain valves opened to allow water to drain clear.

After the generator is stopped, the brushes should be lifted and examined to see that they have worn evenly and have been properly resting on the commutator with the requisite pressure. Every part of the armature should be examined and turned over by hand so that all parts can be seen to see that there have been no abrasions of the windings or evidence of the armature striking the pole pieces. It is well to rest a thermometer on the armature immediately after stopping, covering the bulb with waste, and obtain the temperature before it has time to cool. The armature should be cleaned of all copper dust or carbon dust that may have been deposited from the brushes, removing it with a stiff brush or by hand bellows, making sure that it is dusted off and not driven into the windings of the armature out of sight.

The main switch on the generator or the circuit breaker should be opened and all resistance taken out of the shunt-field regulator. The self-oiling bearing on the generator end should be examined occasionally, the rings cleaned, old oil replaced by clean oil.

The commutator should be examined for any signs of undue wearing, cutting or burning and any evidence of the formation of high or flat bars, and the insulation examined to see if there are signs of its rising.

If there have been any signs of weakening of insulation, the whole machine should be tested after every run, so that the weakening may be properly followed and corrected before it is too late. This can readily be done in a few minutes by a voltmeter connected to the mains of another running machine, or from live bus bars on the switchboard. By connecting the two terminal leads of the voltmeter to the various parts and windings, and noting the fall of potential, the insulation resistance of all the parts can quickly be measured. The calculation is from the formula

$$I.R = \frac{V \times R}{V'} - R,$$

where V is the potential across the mains of the running machine. V' the reading when connected between a live wire and any one of the various parts or windings of the machine, and R the resistance of the voltmeter.

After stopping, the governor should be examined to see that none of the parts stick, and the parts wiped off with clean rags to prevent the formation of gummy substances that would interfere with their free working.

All connections should be looked at, and loose ones tightened, and especially the connections of the different field windings, which are apt to be loosened by excessive vibration. Circuit breakers should be examined and their working parts tested.

After the machine has cooled and been turned over by hand to see that no tools or cleaning gear have been left to jam running parts, a cover, if furnished, should be thrown over the set to keep out dust or dirt.

Starting the Set.

Assuming that all the precautions stated above have been taken, a generating set should be ready to be started at an instant's notice, the only time required being that necessary to warm up the engines.

Make sure that the cylinder drains are open, and if a compound engine that the drain from the receiver is open. Open wide the exhaust valve and the engine stop valve. Turn the engine over by hand once or twice to make certain that nothing has been left to injure the moving parts. If not fitted with forced lubrication see that the oil feeders are opened and that the drip is properly regulated. The expansion of valves is usually more rapid than the cylinders, and the cylinders should reach the proper temperature before the full steam pressure is allowed to enter. Crack the throttle valve slightly and allow steam to enter the valve chest and cylinder, and turn over once or twice by hand to allow the steam to take its full course and warm all parts. In the compound engines there is a small pipe from the throttle to the receiver which should be opened to help warm the engine.

As the parts warm up, if there is no particular hurry to get current on the machine, the throttle valve can be gradually opened and

the engine speeded up, noticing any leaks in stuffing-boxes or glands. After the engine has run at full speed for a few minutes, the brushes may be lowered on the commutator, if fitted that way (in most machines the brushes rest on the commutator all the time), being careful to fit the side or lower brushes first, leaving the upper ones to be lowered last. As soon as both brushes or sets make contact, it is probable that E. M. F. will be induced, and the handiest brushes to get at should be set last. The field due to the shunt windings will then build up and the voltage, shown on the voltmeter and by the glowing of the pilot lamp, will attain its full value, the resistance of the regulator being increased as the current rises. The main switch or circuit breaker can be then closed and current delivered to the switchboard, all circuit switches being left open. The outside circuits can then be thrown in one at a time, the brushes being examined for undue sparking and rocked accordingly to reduce it, and any change in the voltage being rectified by the shunt resistance.

After the engine has been running for some time and it is apparent that the cylinders are free of water, the drain valves may be closed. If any water hammering occurs after the engine is started, it can generally be stopped in the compound engine by admitting live steam to the receiver and low-pressure cylinder.

During the running, care should be taken to see that the oil feeders are working properly; feeling all the bearings with the hand from time to time for undue heating. If self-lubrication is used, the oil gauge should be connected to see that the feeding is under the proper pressure, from 5 to 20 pounds. After all the switches are closed on the switchboard, there will not be much change of load unless motor circuits are connected up, when the brushes may require some attention due to the extra load, and the ammeter should be watched to see that the machine is not overloaded.

Stopping the Set.

If the load carried by a running generator which is to be stopped is necessary for lighting or power purposes, it should be transferred to another machine that has already been started and built up; the

circuits being thrown over one at a time on the switchboard. If the load is not necessary, the generator can be stopped without throwing off any of the circuits and this plan should be followed where possible. The speed is slowed by gradually closing the throttle, and as the speed falls, the induction and current drops, gradually lessening the load on the machine and all lamps and wiring accessories. After the throttle is closed, then close the engine stop valve, open the drains and when the engine is entirely stopped, close the exhaust valve. As the voltage drops, throw out the resistance of the shunt field, and when current is sufficiently off, open the main switch or circuit breaker. If the brushes are fitted to raise, lift them clear of the commutator; if not, of course they require no attention. Then proceed as in the case given jut before starting.

Care of the Commutator.

As the commutator of a continuous-current machine is the most vital part, the utmost care should be given to its condition when not running, and it should be watched constantly when running. for under certain circumstances a few bad minutes may be sufficient to ruin it. Brushes must be so set that the pressure is not sufficient to gouge or score the commutator bars, while making such good contact that injurious sparking will not result.

The commutator should not be oiled, and if any lubricating is necessary it can be wiped with a clean oily rag or a piece of cotton on which a small quantity of vaseline has been smeared; never use waste, as particles are apt to be torn away and stick to the commutator. If oil is used on the commutator it is apt to char under the brushes, forming a film between the commutator bars, and flying particles of copper or carbon from the brushes may stick to it, and if very bad might short circuit an armature coil. Never put oil where it is not necessary and make sure if handling oil that none gets on the commutator or near the armature coils, for it may rot the insulation, besides making a lodging place for flying dust of all kinds. One good way to lubricate the commutator is to make a strip of canvas about the width of the commutator and put a little vaseline on one side, smearing it with the finger all the way across. Then when the machine is running and the brushes raised, press

the canvas with the vaseline side against the commutator. This is a very good way also of cleaning the commutator of any gummy composition that may lodge on it, using a plain strip of canvas, but for this purpose it should be rather coarse.

When running, the great thing to be borne in mind is that there shall be no sparking on the commutator. This fault has been reduced to a minimum in recent machines, the brushes requiring no change from no load to full load, but it should be kept constantly in mind and watched for, and signs of sparking in recent machines may mean something more than injury to the commutator.

The commutator of modern well-designed generators should acquire, with proper care, a beautiful dark-bronze polished surface, and this is not to be taken as an indication of dirt that should be removed; and a clean bright highly-polished commutator may mean one that has too much care. Too much care may mean too much use of the file or sandpaper, which should be avoided whenever possible.

If the commutator has been allowed to get rough or burnt at the leaving edges, it may be necessary to smooth it down with a fine file, but this should only be done by an expert, for in inexperienced hands it becomes worse than which it is intended to correct. Care must be taken to see that an equal amount is taken off all over to avoid any tendency to eccentricity. Fine sandpaper fitted on a block of wood to the curve can be used as a finishing touch to work down any rough places left by the file. Never use emery of any description, as the flying particles are good conductors and may lodge between commutator bars and bridge them over.

If a commutator becomes so badly worn or scarred as to make sparking still more injurious and the heat formed a source of loss, it is better to place the armature in a lathe and turn the commutator down true with a tool. This should be done while the armature is rapidly revolving and with a fine-pointed sharp diamond-faced tool. Only a fine cut should be taken each time and the feed of the tool should be very slow, and only enough metal taken off to insure perfect symmetry. After the tool is used, the final finishing may be done with a dead smooth file, and all particles of copper carefully removed from between the bars.

Care and Setting of Brushes.

The proper position of brushes depends upon the particular winding, internal connections, cross connections, etc., and it should never be assumed that the proper position is known, but the directions furnished by the makers should be followed.

In many of the four-pole generators used in the service the armature is cross-connected, necessitating but one set of brushes set 90 degrees apart, the neutral position being between the poles. In a late design of six-pole machines there are three sets of brushes, the armature not being cross-connected, set 120 degrees apart and under the poles, the three positive and three negative brushes each being connected in multiple. In this machine, there is a reference mark on the pedestal and one on the brush-holder yoke, and when they are in line, the brushes are in the right position. If the brushes are in the exactly opposite position from what they should be, the machine will not build up at all, so a little experimenting will serve to show the correct position. The brushes should be set in a generator a little forward of this position, and in a motor a little backwards from it; this shifting being necessitated by the armature reactions which distort the field magnetism to a certain extent.

Of whatever material brushes are made they should rest evenly on the commutator with sure but light pressure, about 1½ pounds, and anything above that merely serves to increase the friction; the resistance per unit of area beyond that being not reduced. If brushes are made of copper, they are usually fitted so as to make an angle with the normal to the commutator, the angle depending on the construction of the brush holder and the position of minimum induction. This necessitates the ends being filed at the proper angle, and this is sometimes accomplished by placing them in a jig, a metal box mitered at one end to the angle desired, and the brush is filed down to this angle. After being filed down these are put in the brush holders in place, and they soon smooth down by being run on the commutator, the latter being harder and wearing away the rough edges of the brushes.

Carbon brushes are usually set normal to the commutator, and are fitted for a pressure of about 1½ pounds as stated above. They

are fitted to the curve of the commutator by passing beneath them fine sandpaper, held sand up against the surface of the commutator. Or the sandpaper may be pasted on the commutator and the brushes pressed against it while the armature is revolved, or the sandpaper may be passed between the brush and the commutator and drawn in the direction of rotation of the armature, the brush then raised, the paper replaced under the brush, which is then lowered again on it, and the operation repeated until a perfect fit is obtained. Carbon brushes require less attention than copper; they do not cut the commutator and their resistance prevents the development of sparking, but this resistance causes them to heat more than copper, and they must be larger to carry a given current than the copper. At times one of abnormally high resistance may cause sparking, due to the fact of not making good contact with the commutator.

Brushes should be set to cover as much as possible of the commutator surface, the positive and negative ones breaking joint with one another, and they should be shifted at times slightly along the commutator in the direction of the length of the bars.

Care of Brush Rigging.—The brush rigging consists of the brush holders, supports for same and cables.

The brush-holder supports are of two kinds: adjustable, i. e., allowing rotation of the brushes on the commutator, and fixed, allowing no such adjustment. The former type is used where exact adjustment under operating conditions is necessary and which cannot be predetermined in design. It consists of a ring or yoke carrying all brush studs, turning on a seat concentric with the shaft. The exact position of this yoke is determined at the time of installation and the punch marks upon it and the stationary part of the machine indicating the proper position, which should always be kept in line regardless of the load.

The effect of moving the brush yoke of the motors from the position thus designated is to alter their speed and cause sparking.

Another type of rigging has the brush studs rigidly held by insulating supports from the frame of the motor, allowing no angular adjustment of the brushes, but provided with means for moving the brushes toward the commutator as the latter wears.

The studs supporting all brushes on the turning yoke are insulated therefrom by bushings and collars and are held in place by nuts. Care must be taken that these nuts never loosen, allowing the studs to turn and thus lift the brushes from the commutator. These nuts may possibly work loose after having been properly set up, and frequent inspection must be made to prevent such from occurring.

Nothing is gained by increasing the pressure per square inch on a carbon brush above two pounds, as the resistance per square inch beyond this point is practically not reduced, whereas the friction is increased in direct proportion to the pressure.

The tension may be determined by a small spring balance carrying a flat hook which should be slipped between the center of the brush and the commutator. The brush should then be pulled directly away from the commutator, care being taken that it does not bind in box, until it just leaves the same, the tension on the brush being given by the reading of the balance.

Always use the pressure of the spring upon the brush, instead of that of the hand, when fitting with sandpaper, because if the hand is used the brush may be forced to take a different position from that derived from the spring pressure and consequently not to be fitted to the commutator as it should be for proper contact when machine is running.

If the brush requires considerable sandpapering, No. 2 sandpaper may be used at first, but the final fitting must be done with No. 0. If an attempt be made to fit the brushes without raising them when drawing the sandpaper back, it will in every case fail to give satisfactory results. When thick brushes are used, in addition to following the above instructions the machine should be run as long as convenient without load in order to improve their surface.

Care of Engine.

In this, as in all other parts of the electric installation, the first requisite is cleanliness. All parts of the bright work should be kept bright and polished, free from oil and grease except where needed, and the paint work clean and free from soot and grease spots.

It is well to establish a routine for the overhauling of the engine parts, and not assume that because everything is working well, it is going to do so forever without care and time spent on it. The bearings and journals should be regularly examined, the caps removed and examination made for any gritty substances that may have been carried in by the oil. The feeding holes, or if self-lubricating, the feeding pipes, should be unscrewed from time to time and thoroughly cleaned out, as they are apt to clog after constant use. Special attention should be given to the babbitting of the bearings, making sure that it is wearing and bearing evenly, and that it is renewed in plenty of time.

The piston-rod and valve-rod packings should be constantly watched and on steam leaks developing they should be taken out, cleaned or renewed; the modern form all being of metallic type. The cylinder heads should be taken off about once a month, and the inside of the cylinders and pistons examined. The cylinders should be given a light coating of a mixture of vaseline and plumbago for lubrication, oil not being used in the steam spaces except under special circumstances.

It is well not to touch the governor as long as it is performing well, for this is a most important piece of mechanism, and overhauling is more likely to do harm than good. When it fails, the remedy should be sought and applied, particular attention being given to the tension of the spring.

The drain and relief valves should be occasionally unscrewed, the springs cleaned and the valves properly seated and it may be necessary at intervals to regrind them.

Particular attention should be given to any noise or knocks that may develop during running. Every noise must have its cause and it should be at once remedied, by setting up on cross-head bearings or taking up lost motion or tautening on eccentrics, and experience alone can determine the particular kind of noise caused by any given fault.

In simple engines, the valves should be so set that each cylinder is doing an equal amount of work, and in compound engines that the two cylinders are each doing their proportionate share. This can only be ascertained by taking indicator cards which should fre-

quently be done and the horsepower of each cylinder calculated. Besides the power developed the cards will also show whether the valves are set for the proper lead and lap, and the general compounding of the engines. Cards should be taken at different loads on the generator and the voltage and current noted at the same time, in order that the net efficiency of the set as one may be determined.

Each engine is supplied with a full set of tools, wrenches, spanners and the like and each has its particular use, and they should be used for that purpose and for no other, and never allowed to be taken away from the dynamo-room.

General Care of Dynamo-Room.

The old rule, "A place for everything and everything in its place," is particularly applicable to ship's dynamo-rooms. Tools should not be left on work benches or lying around the room, but each should be kept in its particular place, a tool board being furnished, and all metal tools should be kept bright. Small articles should have a place in a locker drawer and on no account should they be left around or near the generators where they are liable to fall in the moving parts, out of sight, to be heard of later when they have done some damage.

Clean waste should be kept in its own tank, and all oily waste should be kept in a separate receptacle, which should be emptied at least once a day. Oil cans and feeders should be always polished and kept free from oil on the outside. Copper oil tanks, if fitted in the room, should be kept bright. The switchboard should be kept immaculately clean and copper conductors kept polished. Moisture should be removed at once whenever it appears on any part of the switchboard appurtenances, and the glass faces of instruments should be kept polished. The paint work of the dynamo-room should be regularly cleaned and scrubbed as well as the paint work on the lagging of all pipes and valves, as well as the engine paint work. All parts of engine bright work should have a dry high polish and be kept free from oil or moisture.

The care bestowed on the floor of the dynamo-room depends on its character, but it must always be remembered there is more or less oil and grease tracked around, and the floor should be scrubbed

at times with lye water. If fitted with wire matting, that should be taken on deck, swept with a hard brush and scrubbed. If wooden gratings cover an iron deck, it is well to have them covered with deck cloths, well shellaced, to be used for ordinary wear, taking them up for inspection.

A great deal of the oil and dirt of former days is done away with by the use of self-lubricating mechanism, and with care and a little attention, the dynamo-room should be made one of the cleanest parts of the ship.

Care of Wiring Accessories.

The greatest single cause of the breakdown of wiring appliances is undoubtedly water or moisture, and this should be removed at once, wherever and whenever it appears. The great aim has been to make all appliances, or at least all of those subject to exposure, water-tight, but the greatest care must be exercised to see that they remain so, and all evidence of moisture on appliances whether supposedly water-tight or not should not be allowed to remain.

General Effect of Moisture.—Moisture on electrical conductors lowers the insulation resistance and if allowed to remain will eventually rot the insulation and destroy it. Moisture mixed with dust or dirt forms a film of conducting material which is objectionable on all appliances, and the same may be said of oil and dirt of all kinds.

Moisture may come from water thrown directly on appliances, such as those exposed to rain or to sea water thrown over the side, or from condensation from the air due to changes of humidity. Excessive condensation sometimes occurs in the dynamo-rooms when the engines are started after everything has become cold.

All moisture tends to electrical leakage and the effect is to offer a path of low resistance which may injure the conductor. A high-resistance leak may cause trouble by the heat produced or cause corrosion of the wires by the electrolytic action of current of the water.

Salt water is more to be avoided than fresh, partly because it is a better conductor and because it deposits salt on surfaces which will tend to corrode by electrolysis, and in addition, the salt left

behind will attract moisture from the air. Salt-water moisture should be wiped off twice, once to remove the water and the second time to remove the salt. Any recurring source of moisture should be noted and watched, the source found and corrected. Moisture on generators, motors, switchboards and the like should be carefully wiped dry and tested for any excessive leak to ground. Moisture may often be removed from bared conductors by passing a current through them, starting with a small current and gradually increasing it, the heat evaporating the moisture.

If by any chance armatures of motors or generators become damp they should be run for some time without load, allowing the heat to gradually dry them.

Care and Management of Circuit Breakers.

Type M. Q.—This circuit breaker is very simple in construction and requires but little attention, and there are but few matters to be specially borne in mind in operating and caring for it.

1. All bearings should be well lubricated and work freely.

2. The contact fingers must always bear evenly upon the segment or heating will result. When inspected, it is well to slightly lubricate these contacts with vaseline, but care must be taken that too much is not used.

3. The burning contacts above the fingers must never be allowed to be destroyed, as the arc will then be formed upon the fingers and ruin them.

Type M. L.—The parts to be specially looked after in this circuit breaker are:

1. The main brush contacts, which must be kept clean and bear evenly on the contact studs.

2. The position of the armature when the circuit breaker trips. There should be $\frac{1}{16}$ of an inch space between the bottom of armature and top of fiber piece on coil when the breaker trips.

3. The secondary contacts must be kept in good condition and care should be taken to see that they make good connection until the main brushes have well cleared the stud. In adjusting the secondary contacts, see that there is between $\frac{1}{8}$ and $\frac{3}{16}$ of an inch space between the moving plug contact and the fixed contacts on the side

of the fiber chute when the circuit breaker is open. This adjustment is made by removing the top pole piece and fiber cover of the chute, when the secondary contact is exposed. Also, in renewing the secondary contacts, see that all set-screws and connections are firmly set up, as a loose contact in this circuit breaker may destroy the main brush.

If the main brushes should become burned so that it is necessary to dress them with a file, see that they are so filed and adjusted to the stud that the outer tip of the brush just comes in contact with the stud when the heel of the brush is $\frac{1}{32}$ of an inch away. This insures that every lamination of the brush comes in firm contact with the stud when the circuit breaker is closed.

Keep the armature pivot and brush holder well lubricated, also all joints connected with the tripping catch. It is well when examining the secondary contacts to slightly smear with vaseline. This prevents the cutting action and increases the life.

Care of Fuses.

To Install or Replace a Fuse.—Open the switch controlling the circuit the fuse protects.

Stand on insulating material; do not touch grounded metal and if possible use insulated tools. A slight shock might cause the dropping of a tool that might short circuit other parts of the circuit.

Do not allow the screws holding a fuse to fall, as they are liable to lodge in some place where they might short circuit a live circuit.

In replacing fuses, set up on one end lightly, keeping the other end pointed away from its contact, then swing the free end to its contact and set up on both screws.

Branch fuses can be replaced without opening the switch on the circuit, the glass being held firmly in the middle and pressed squarely into the contact clips. It is well to light up the interior of the box by an outside light so there will be no danger of touching the wrong clips and melting the fuses.

In working near switchboards with screw-drivers it is well to wrap all the blade except the tip with tape to prevent accidental short-circuiting and one working with the body close to switchboards and especially near bus bars should not wear watch chain which might rub against the bars and cause momentary short circuits.

Care and Management of Rheostats.

Three points should be particularly observed in the care of rheostats:

1. All electrical connection should be tight and clean.

2. The filling should not be overheated so as to destroy the conductor or its insulation. This is something which is not likely to occur, as the rheostats have been designed with special reference for the work to be performed and should give no trouble except in extreme cases of careless operation.

3. The rheostats should be kept dry. Moisture absorbed by the asbestos insulation will cause leaks and short circuits, and it is essential that particular care be taken that no water enter the rheostat. The fillings are protected by a coating of japan to protect them from moisture. As this japan may be injured by extreme heating, the rheostats should be occasionally inspected. If the japan is found to be injured the filling should be painted with it. When the panels are freshly painted, a moderate amount of heating will cause them to smoke, but this does not indicate trouble unless the smoke should be excessive. The smoke from newly-painted rheostats will ordinarily disappear after the rheostat has been used a few times.

Care and Management of Controllers.

It is essential that the separate parts of all controllers should be kept bright and clean. Bearing should be occasionally lubricated with oil and contact rings occasionally lubricated with vaseline, but pains should be taken not to use too much, as it is apt to increase the burning and the blackening of the contacts. Care should be taken that the gaskets of controllers having water-tight covers should not become broken or loosened, but that they should always be in place and the cover tightly clamped. Attention should be given also to the bushings surrounding the lead wires, where they come through the frame of the controller, to make sure that they have not slipped out of position. The stuffing-boxes at the top, when such are used, should be kept well packed, so that water will not enter around the shaft. Controllers are generally provided with a projecting brass ring, called a water cap, which, while not

being absolutely water-tight, answers all ordinary requirements of the water protection. The projections on the shafts and other bright steel parts should be occasionally slushed to prevent rusting. All screws and check nuts should be kept thoroughly tight, as a loose electrical connection is likely to produce excessive heating.

Adjustment of Contact Segments and Fingers.—Care should be taken that the contacts and fingers are kept in good condition. They should always present a smooth appearance, except that the tips of the contact rings and the fingers will be slightly burned and roughened through continued use. A small degree of roughness is expected, but it should not be allowed to be so great as to interfere with the easy mechanical operation of the controller, or with the electrical connections. The contacts should be frequently inspected, and the fingers and contact rings filed, if necessary, to remove any rough spots, so that when on any notch of the controller, the finger where it makes contact with the line ring, will make contact across the whole width of it, and not in a single point.

If the rough spots are so bad that they cannot be easily filed smooth, the contact ring or tip should be replaced by a new one. In some cases, as already explained, the segment will have to be replaced, while in others a short tip only is removed, leaving the main part of the contact undisturbed. When replacing the contacts, take care that the surface of the back of the contact and of the outside of the cylinder castings are bright and clean. The screws supporting the contact rings should be set down sufficiently to make a firm contact, but it is very easy to set the screws too hard, in which case it will be difficult to remove them later, after replacing contacts.

Fingers are easily replaced by taking out the small screws fastening the spring to the finger base. This spring is bent so as to give about the correct tension when screwed down firmly in place, but the fingers should always be tried by hand to make sure that the tension, when pressing upon the cylinder contacts, is correct. This tension, for 1-inch fingers, should be about three pounds, that of the smaller fingers being correspondingly less. A set-screw is provided with each finger, bearing upon the projecting lug of the finger base. This screw should be turned until it allows the top

of the finger to drop about $\frac{3}{32}$ inch below the surface of the contact finger of the cylinder. The check nut should then be firmly set, taking care not to twist the spring of the finger by so doing. If this distance is greater than $\frac{3}{32}$ inch each, the contact fingers are likely to interfere with the free movement of the cylinder, as the ends of the fingers will strike against the ends of the segments, and if the amount is less than $\frac{3}{32}$ inch the fingers will not drop sufficiently when the cylinder contact leaves it to bring the burning in the proper place. As it is essential that the surfaces making electrical contacts should be kept smooth, it is necessary that the burning should take place at some other point, and this is accomplished by this movement of the finger, causing the actual burning to take place near the top, beyond the line of contact of the contact finger at the end of the round.

While a roughness at the extreme tips of the contact fingers and contact segments does not impair the electrical contact at the working points, still it makes the controller more difficult to operate and makes the break between the finger and contacts uncertain and uneven, so that it is important to keep the surfaces as smooth as possible. In adjusting the fingers, the springs should be bent, if necessary, by a small wrench, so that the finger will bear upon the contact ring throughout its entire width, and not at one corner only.

It is important that all the fingers which make or break electrical connections with the contact rings on the first position of the controller should do so at the same instant, or as nearly so as possible. It is not always possible to accomplish this absolutely, because the fingers may vary slightly in shape, and if the fingers are adjusted to make exact contact on one side of the cylinder, they will not do so on the other side, but this difference should be equalized as much as possible between the two sets. This adjustment may be made by turning the cylinder toward the first position until the contact rings touch the cylinders, and after a little practice it will be easy. Note whether any of the contact fingers are lifted by the contact ring before the rest, and all such should be raised slightly with the adjusting screws until all of the fingers are observed to rise and fall together, but in making this adjustment the dropping distance of $\frac{3}{32}$ of an inch should not be much increased or decreased. If

this becomes necessary, it shows that the contact point of the finger is not at exactly the right distance from the spring. This can be remedied by taking off the finger and either straightening it with a hammer or bending it slightly more. If it is found, after making an adjustment of the fingers on one side, that they do not make contact together on the other side, those that touched too late should be let down, and those that touched too soon should be raised up until about the same amount of difference occurs on both sides of the controller; but a finger which touches too soon on one side will touch too late on the other.

When the contact fingers are properly adjusted as above, a nearly equal sparking should occur at all of these contacts when the cylinder is turned off, and this forms an additional test of proper adjustment. If one finger should draw considerably more arc than the rest, it shows that it breaks contact a little before the rest. It is not expected that the sparking at all points can be made exactly the same, or if so, that it will always remain so, but it should be approximately equal. In this way the burning of all fingers is reduced to a minimum.

Operation.—In using the controllers, special care should be observed to make the changes of position quickly, as the burning of the contacts is very much reduced. This should be observed, both in making and breaking the circuit, but especially in breaking it. If two electrical contacts carrying a current are pulled apart slowly an arc will be formed which may be continued for some time, but if they are pulled apart very quickly to the proper distance, the arc will last but an instant. The position of the cylinder being indicated by the star-wheel, it is very easy to tell how far the cylinder has moved.

Care should always be taken that the cylinder should stop only in points corresponding to notches on the star-wheel, as otherwise the controller might be held up with the contacts separated so little that the arc would continue. In turning the controller from the off position the pressure of the cylinder contacts against the ends of the fingers will be felt before the first notch of the star-wheel is reached. This offers about the same amount of resistance as the star-wheel notches, and unless care is taken it may be confused

with one of these notches. Particular pains should therefore be taken that in turning to the first position the cylinder actually reaches this position and does not stop when the first blow of the contacts is felt.

Although the controller should be turned quickly from one notch to the next, it does not follow that a controller should be turned rapidly from the off position to the full-speed position. To do so would cause an overload, which might open the circuit breaker. It is therefore advisable that several seconds be taken in bringing the motor up to full speed, the actual length of time depending upon the size of the motor. In the case of the larger motors, five seconds should be sufficient to bring the motor up to full speed; in the smaller motors, two or three seconds. The proper way is to pass quickly each notch, pausing an instant on the notch before proceeding to the next one. In turning the controller off to stop the motor, in most cases the cylinder can be turned instantly to the off position. This can be done in all cases of series motors, but in the case of the shunt motors, when lowering heavy loads, or in lifting very light loads, it is better to turn off the controller more slowly. If a light load is stopped too suddenly, the momentum of the armature, if it is short-circuited on the off position, will produce a rush of current which may tend to burn the brushes and put too much mechanical strain on the motor and the mechanism to which it is connected. This should be observed with special care in the case of the turret controller, as the momentum of the turret is so great that it should not be started or stopped suddenly. In lifting a heavy load with an ammunition hoist, there will be no great difficulty in stopping the motor from full speed instantly. A sudden stop is not recommended when the empty cage is being lifted.

Care and Management of Turret-Turning System.

The following description applies to motors controlled by the Ward-Leonard System of Control.

Equalization of Load between Motors.—If it is found that one motor is taking considerably more current than the other when both fields are approximately the same temperature, and so far as

is known, no resistance has been inserted in either field, after going over all connections and making sure that the trouble is not due to a loose contact, the load should be readjusted by moving the brush yoke upon the motor which is taking the greater load.

This adjustment can only be made by trial, and after moving the yoke a small amount in one direction, the turret should be revolved and the effect noted on the ammeters. This operation should be repeated until the current through each motor is the same.

The current in the motors should not differ more than 15 or 20 amperes; but even when they run with exactly equal currents when the turret is revolved in one direction, a greater difference than this may occur when the direction of rotation is reversed. Unless the constant difference is more than 40 to 50 amperes no attempt should be made to equalize the load.

If the two motors should tend to run at widely different speeds, one may drive the other as a generator. This would be immediately apparent on the ammeters, one of which would read in the opposite direction from which it should.

Lubrication.—The self-oiling bearings of the motor should be kept full, frequent examinations being made, however, to see that no oil is working into the motor case.

Order of Operating Apparatus—Using Main Generator to Start. — In the turret:

1. See that the controller is in the *off* position, that the current breaker is open, and that the field and armature switches are closed.

In the dynamo-room:

2. See that all switches and circuit breakers on the system connected to the generator to be used, are open. These are:

(a) Generator panel circuit breaker.

(b) Equalizer switch. (*Never close* this switch when operating a turret.)

(c) All switches on the generator panel.

(d) Armature and field switches on the power panel board.

3. Close single-pole series field switch at bottom of panel, for the machine to be used.

4. Close single-pole switch to common negative on panel of machine to be used.

5. Close single-pole switch to positive turret bus bar on panel of machine to be used.

6. Close field switches for turret to be operated on panel of machine to be used for operating it.

7. Close double-pole motor-field switch on main power panel.

8. Close single-pole switch on the main power panel in negative side of generator—motor-armature circuit.

9. Close circuit breaker on top of generator panel.

In turret:

10. Close circuit breaker in turret.

11. Operate controller. (See following instructions:)

To Stop.—In turret:

1. Throw the controller to the off position.

2. Open circuit breaker in the turret.

In dynamo-room:

3. Open the circuit breaker on the generator headboard.

4. Open armature switch on main power board.

5. Open the field switch on the main power board.

6. Open all switches on the generator panel.

7. Stop engine.

Directions for Operating the Turret Controller.—The turret should not be accelerated too rapidly as this requires an excessive current and will result in blowing the circuit breaker. Practice will soon give the operator a knowledge of just how quickly it may be brought up to speed, and then no trouble will be experienced with the circuit breaker, which will only act as intended in case of accident. The circuit breaker should *never* be closed until the controller is brought to the off position, as a sudden load would be put on the system causing the circuit breaker to open again.

In starting from rest, the controller wheel should be quickly moved to the first notch, or until the armature circuit is closed. After that, the rate of movement is immaterial, as the only circuits opened and closed are those of the field of the generator, which carry a small current only, and the circuit breaker is thus the governing factor.

In stopping the turret, the controller wheel may be rapidly turned

to the first notch, thus causing the motors to generate current and thus retard the motion of the turret. When the speed of the turret has been materially reduced, the controller may be thrown to the off position, in which the brake circuit becomes operative and the motors stopped. By this method the arcs at the controller fingers are diminished, the wear on the friction discs is reduced and excessive strains are not brought to bear on the armatures of the motors.

In starting the turret when very fine arcs of train are required, the controller wheel should be quickly revolved to the second notch or thereabouts and immediately returned to the off position, allowing the brake circuit to act. Under no circumstances should the controller wheel be thrown beyond the off position to reverse the motors before the turret has stopped as this will certainly open the circuit breaker.

In case of failure of power, throw the controller at once to the off position and investigate the cause. As the circuit breaker in the dynamo-room may cause this, by opening, and as the operator may close it immediately, it is essential that the controller be *at once* thrown to the off position to prevent an excessive rush of current when this closing takes place.

Cautions—Using Main Generator.—

1. The equalizer switch must never be closed.

2. The motor-field switch must *always* be closed before the armature switch.

3. In case one motor in the turret must be cut out, open the armature switch first and then the field switch in order that the armature may never receive current without an excited field.

4. No switches on the generator panels should be closed for turret turning except those for the turret to be used.

5. The series-field shunting switch should always be open when the generator is not operating a turret.

6. The turret must not be accelerated too rapidly, and the circuit breaker in the turret must never be closed until the controller is at the "off" position.

7. The controller should not be rapidly thrown to "off" position when the turret is running at full speed, except in cases of emergency.

8. If the armature current fails, the controller should immediately be thrown to "off" and the cause of the trouble investigated.

9. Never reverse the direction of the motors until they have first been *stopped.*

Care and Management of Turret-Ammunition Hoists.

Solenoid.—Oil holes are provided in the top of the solenoid casing. These should receive attention when running, and if the brake shows a tendency to heat, oil should be used.

To start:

See that the controller is on the off position and the circuit breaker open; then:

1. Close switch on power panel in dynamo-room. (This excites the auxiliary distribution boards in the turret.)
2. Close double-pole switch on panel.
3. Close circuit breaker.
4. Operate controller. (See directions below.)

To stop:

1. Throw controller to off position.
2. Open circuit breaker.
3. Open double-pole switch on panel.
4. Open switch on main power panel in dynamo-room.

Directions for Operating Controller.—

1. Turn the handle to lower, as marked on the dial plate.

2. Throw handle promptly from the off position to first notch, and do not let it stop when the fingers first touch the contacts or an arc will be started and the fingers roughened; also be careful not to move past a notch and then return to it or an arc will be drawn.

3. When starting the hoist do not accelerate the car too rapidly, but make a short pause on each controller notch. If too rapid a start is made the current will jump to very large values and open the circuit breaker and roughen the fingers.

4. When stopping the car at the bottom after lowering, do not try to stop suddenly from full speed, as the rush of current when the armature is short-circuited at the off position will be excessive.

5. When stopping the car at the top after hoisting, throw the handle quickly to the off position, as at this position the solenoid brake sets and holds the load.

6. If the circuit breaker acts, throw the handle immediately to the off position.

Care and Management of Chain-Ammunition Hoists.

Hoist and Gearing—Lubrication.—

1. The sprocket wheels, chain links and gears should be slushed with a mixture of graphite and grease.

2. All shaft bearings should be oiled by hand as use requires.

3. The hand gear sprockets and chains should be oiled and turned over at intervals to prevent rusting.

4. The upper sprocket wheels, which turn on fixed pins, are provided with oil holes.

Adjustment.—

1. Any stretch or slack in the sprocket chain can be taken up by screwing down on the adjusting screws of the bearings of the sprocket shaft.

Solenoid Brake.—The brake should be so adjusted, by means of the turnbuckle at the end of the brake band and the nuts on the vertical rod supporting the movable case, that when the magnet is released the cores do not fall more than $1\frac{1}{2}$ inches, and when the magnet is energized the brake band does not rub on the wheel.

The leather lining on the brake band should be kept clean and in good condition, and the bearing pins in the lever should be occasionally oiled.

Location of Safety Devices.—The location of safety devices which may open the circuit are as follows:

1. Fuses and switch in dynamo-room.
2. Fuses in box in each feeder circuit.
3. Fuses on face of controller panel.
4. Overload circuit breaker.
5. No-load circuit breaker.
6. Switches on controlling panel.

To start:

1. Close switch on panel in dynamo-room.

2. Close interlocking switches on controlling panel in the proper direction, throwing them *up* to hoist and *down* to lower.

3. Move the rheostat arm as far as possible to the right, setting the circuit breaker.

4. Press down on push button and move the arm slowly to the left until the button rests in the raised surface of the contact ring.

If the arm is moved too rapidly, or if the current fails, the circuit breaker will open.

To stop:

1. Open the single-pole, single-throw switch, or pull out the push button in starting arm.

This will release the circuit breaker which is in the side of the line. It is impossible to re-set this until all starting resistance has been placed in the circuit. The single-pole switch should always be left open, except when the hoist is in operation.

2. Open the switch in dynamo-room.

Caution.—

1. *Before starting* the hoist, *always* see that the hoist cover is removed and the delivery table turned out of the hoist and pinned in position, and the wrench for operating the safety pawls removed.

2. *Before lowering, always* see that the safety pawls are raised. Failure to follow these two precautions will jam the hoist and may result in damage to the mechanism.

3. Before hoisting ammunition, always see that the safety pawls are down.

4. Always see that hand gear is thrown out and power gear thrown *in* before starting the motors to operate the hoist.

Care of Boat-Crane Gear.

Lubrication.—

1. The motor-armature bearings should be kept well full of grease and all gears should be slushed as use requires.

2. The solenoid brake should be well oiled through the hole provided to prevent excessive heating.

3. The worm for hoisting and revolving gears runs in oil, and these oil boxes should be kept well filled. These boxes also supply oil to the worm bearings.

4. All other bearings to hoisting and revolving gear are fitted with oil holes.

5. Hoisting blocks and guide sheaves are fitted with oil holes.

6. Main deck bearings are fitted with oil holes for roller bearing.

7. The steel hoisting cable should be kept well coated with a mixture of grease and graphite.

Care and Management of all Ventilation Sets.

Brushes.—In view of the continuous character of the work required of the ventilating sets, special attention must be paid to the brushes to keep them in good condition.

Lubrication.—All motor bearings are fitted with self-oiling rings, oil-pockets, gauge-glasses and stop-cock. The oil-pockets should be kept full to the marks on the gauge-glass. If filled too full, the oil will work over into the machine, which would quickly destroy the insulation.

Location of Safety Devices.—The following safety devices may open the motor lines:

1. Switch and fuse on switchboard in dynamo-room.
2. Fuses on controlling panel.
3. No-load and overload device on controlling panel.

Order of Operating Apparatus.—To start:

1. When a fan is fitted to run at different speeds, turn the field resistance arm at "slow."
2. See the switch on panel board open.
3. Close switch on power panel in dynamo-room on required blower lead.
4. Close switch on controlling panel.
5. Move starting arm from initial position slowly across the armature starting-resistance contacts, until no-load coil holds it in the extreme position.
6. If a variable speed motor, the speed may then be increased by slowly moving the resistance arm from *slow* towards *fast*. When

necessary to reduce the speed, this arm should be moved *very slowly* to allow the fan time to slow down, as otherwise the motor may act as a generator, due to its momentum, and generate a back current sufficient to blow the fuses.

To stop:

1. Open the switch on the controlling panel. The starting arm will take care of itself.
2. Open switch on power panel in dynamo-room.

Bearings and Lubricants—Description and Care of Bearings.

The bearings in electric machines are of four kinds:

Self-oiling.
Sight feed.
Compression grease cups.
Grease.

Self-Oiling Bearing.—This consists of a removable sleeve resting in a support above a pocket in which is placed the oil supply. It is cut transversely across its upper half by one or more slots, in which are placed rings carrying the oil to the bearing surfaces.

These rings are of larger inside diameter than the shaft and rest upon it, the bottom of them dipping into the oil in the reservoir below. As the shaft revolves it turns the rings, thus continually bringing oil from the supply and delivering it to the top of the shaft where it is passed along the bearing out at the ends of the sleeve and back to the reservoir.

Thus the supply is constantly in circulation, all dirt settles to the bottom and clean oil is fed to the bearings.

The oil well is filled through holes in the upper part of the bearings and emptied through oil cocks at the bottom.

The quantity of oil in the reservoir is indicated in a gauge which has a mark upon it showing the height to which the bearing should be filled. The bearing must not be filled above this mark, or the oil will run out of the ends and collect in the machine, causing trouble in the windings.

There is a vent in the top of the gauge which must be kept open or the confined air in the glass tube will prevent the oil from correctly indicating the height to which it has reached in the bearing.

Care must be taken that the oil rings are always in position. They should be frequently examined to see that they are revolving and feeding properly. This may be easily done by touching the ring with the finger, and observing if oil is left upon it, being particular not to introduce dust into the bearing in this way.

The ring must never be allowed to stand still upon the revolving shaft, as a depression will soon be worn on its inner surface, which will prevent it from ever again operating properly.

The covers or plugs for the holes through which the box is filled must always be kept in place to prevent dirt from entering the bearings.

Red Engine Oil is recommended for use with these bearings, and those kinds which will thicken, such as sperm oil, must not be used, as they are liable to obstruct the rings and prevent them from turning.

Sight-Feed Bearings.—These bearings consist of a sleeve resting in the pillow block with a hole on top midway of its length into which the oil is fed from a reservoir above. The oil passes along the shaft to the ends of the sleeve where it is caught and collected in a receptacle.

The oil is conducted through a brass pipe to the bearing, and from it to the receiving tank below. The rate at which it is fed is graduated by the valve in the sight gauge near the supply.

The control of feed is accomplished by turning the milled head on the gauge.

These bearings should be frequently examined for undue heat. Special care should be exercised in this matter with relation to the bearing between the armature and the fan because it supports the latter and is subject to much harder usage than the one at the commutator end; also, it is less accessible and therefore more liable to be neglected.

Compression Grease Cups.—Bearings on certain machines are oiled by means of ordinary compression grease cups. The grease should not be forced from these cups under too great pressure, as it is liable to collect upon and be thrown from moving parts after passing through the bearings.

Grease Bearings.—These bearings consist of split sleeves held in supports, with reservoirs above and below. The upper half of the lining has a horizontal slot allowing the grease in the box to feed to shaft.

The box above should be kept full of grease, which should be pressed down before starting the motor, in order to be certain that it is in contact with the shaft. If this is not done, and the grease has hardened or contracted since the previous run, the bearings must reach a sufficiently high temperature to melt the grease above before it will be lubricated. This delay might cause injury to the linings.

Bearings of this type are frequently mounted upon motors for boat crane, rammers, elevators and whip hoists.

Care of Bearings.—Attention must be given to all bearings while running.

Under proper conditions no reasonable excuse can be offered or accepted for abnormal heating. If it exists, it needs immediate investigation and remedy.

After being in operation a short time, a certain amount of heat is imparted to the bearings by the armature; any undue heating aside from this requires an immediate remedy by the attendant.

The temperature may reach blood heat when running with full load.

Undue heat may result from a variety of causes. Among these may be mentioned insufficient quantity or poor quality of lubricant; dirt or gritty matter in oil or bearing; a badly-scraped bearing; rough journal; caps too tight; an armature shaft slightly bent, or bearings out of line.

If from any cause a bearing becomes unduly warm, a liberal supply of oil may be sufficient to check the heat. If it gets very hot, cold fresh oil will benefit it. It is not advisable to use water on the interior of the bearings unless sure that it is free from dust and gritty particles, although in case of emergency water or ice upon the outside of the box of ironclad motors may be used to reduce the temperature of the bearings.

If the box has a split lining, the cap should be slightly loosened.

If a hot box develops, the shaft should not be stopped immediately, but slowly reduced in speed until the temperature has

fallen to a safe limit. If this direction is not followed, the sleeve is liable to contract upon the shaft so tightly that it cannot be removed except by cutting it off. The shaft is also likely to be injured by such an action.

The cause of the heating should always be ascertained and remedied, and the boxes removed, cleaned, scraped and accurately refitted before starting up again.

After removing the pillow block, or lining, be scrupulously careful in replacing to see that the contact surfaces and dowel pins are free from grit, fibers of waste, or any kind of dirt.

If the bearings should become considerably worn, there is danger that the armature may rub upon the pole pieces. By observing the position of the armature in the field, it may readily be seen whether the bearings are worn down to any considerable extent. If they are badly worn vertically, or horizontally, new sleeves or linings should be substituted.

Lubricants.

The speed at which the machine runs requires a lubricant especially adapted to it.

The value of a lubricant depends upon its power to reduce friction and prevent the excessive development of heat. The characteristics which should be possessed in order to be most efficient as a lubricant are:

1. Sufficient density or body to keep the surfaces between which it is interposed from coming in contact under greatest pressure.

2. The greatest adhesion to metallic surfaces and the least cohesion in its own particles.

3. The fluidity of the oil should be as much as is consistent with the above conditions.

Keep the oil and grease free from gritty matter. All foreign substances injure the quality of lubricants and tend to increase the heating of bearings.

New oil should always be filtered.

The oil in self-oiling bearings should be kept at the proper height by additions, but after a bearing is once in good condition it should not require complete renewal for several months, although judgment is necessary to determine just when a change should be made.

When the oil is renewed, the oil-well should be carefully cleaned and all thick oil and sediment removed.

It is impossible to recommend any one grade or kind of lubricant for continual use because the value of the lubricant depends upon the temperature of the atmosphere where it is used; consequently, a grease which would be satisfactory on bearings below the protective deck, where the temperature might be fairly uniform, would perhaps be entirely unsatisfactory in bearings exposed to the weather, where wide variations of temperature would be expected.

The exact grade of lubricant is, therefore, dependent upon the judgment of those responsible for the plant, it being necessary to use a much harder grease in warm climates than in cold.

Inspections.

The following are given as general directions:

Motors.—Lubrication must be in proper condition.

Brushes must be frequently examined, and see that the screws for holders have not become loose.

Motors should be examined to see that moisture or oil does not collect inside in the bottom of the frame. This is especially applicable to the boat crane and turret-turning motors. If found, it should be removed immediately, and not allowed to drip on the armature or commutator. Drain-cocks are provided in turret-turning, boat-crane and whip-hoist motors.

The motors should be run as often as convenient for a sufficient length of time to allow them to become warm in order to drive off moisture.

Controllers.—The interior of all controllers must be inspected after each time used and all burns or roughness on either fingers or contacts made smooth with a file and fingers properly set as previously described. If this is neglected the fingers may catch on the cylinder making it difficult to move the same, even if in the attempt the finger is not crippled. Too much emphasis cannot be given to this, as neglect might cause a controller to give trouble at a critical moment.

All boat-crane controllers must be kept tight in every way, as water accumulating in them will certainly give trouble.

Rheostats.—Rheostats should be kept dry and as free from dust and dirt as possible. Every rheostat is insulated from the frame of the ship by special bushings to reduce the possibility of trouble at this point. The exposed surfaces should be kept clean to prevent leakage over them and thus make then valueless, and if broken must be renewed.

If a rheostat gets wet it should be carefully wiped and dried before being put to regular use. If convenient it may be dried in a warm room, but if not, then by care it may be gradually warmed by allowing a current to pass through it until all moisture has been expelled. This may be done after it has been ascertained that dampness is the cause to be removed, by placing the rheostat in a circuit which will not allow more than one-fourth of the usual current carried by the rheostat to pass, and as the temperature rises and no trouble develops, gradually increasing the current until the normal amount flows. It may be left in this way until all moisture has been expelled. All dust should be removed as far as possible, and for this purpose a bellows or blast of dry air is very convenient.

Circuit Breakers.—All circuit breakers should be examined at least once a month to see that the bearing contacts are in proper condition, and that all other parts are in good condition.

Covers for circuit breakers in boat cranes and whip hoist must be kept water-tight and should be examined frequently to see that such is the case.

Important Instructions for Operation.

There are certain general operations which should invariably be done in the same manner when managing electrical apparatus and which have been given in the preceding under the heads of different appliances described. These are collected and given below in two lists, "Always" and "Never," in order that they may more easily be remembered and referred to.

"Always."

Always close the field switch before the armature switch.

Always open the armature switch before the field switch.

Always open switches carrying field currents slowly, allowing the field discharge to dissipate at the contacts.

Always close switches provided with field-discharge resistances as far in as they will go.

Always open the series-field shunting switch on the main switchboard after operating a turret.

Always throw a controller to the "off" position immediately when the circuit breaker opens.

Always see that the arm of the automatic release rheostat on controlling panels comes to the "off" position when the main switch is opened.

"Never."

Never close a series-field shunting switch on the main switchboard unless the generator is to operate a turret.

Never run a controller between notches.

Never trip the automatic overload on a ventilating motor-controlling panel to shut down the motor.

Never open the field circuit of a motor while the main switch is closed.

Never hold the car of a 12-inch ammunition hoist on any controller notch but the "off" position.

Never run a 12-inch gun-elevating motor at full speed when near the end of its train, or when depressing an empty gun or elevating a loaded gun.

Never start an ammunition-hoist motor until the hoist cover has been removed and the delivery table turned out into position.

Never start an ammunition-hoist motor in the lowering direction until the safety pawls have been raised.

Care of Switches.

Blisters and burns should be removed from all switches as soon as they appear, as they make poor contact when the switch is again used and increase the resistance.

The joints of knife switches should be sufficiently tight to hold

the blade in any position in which it is placed, but not so tight they cannot be conveniently opened or closed.

Circuit switches should be thrown quickly in either direction to prevent arcs being formed which injure the contacts. When opened the switch should be fully open and the blades not left near the clips.

Turret-field switches should be opened slowly to allow the induced current of the motor field to discharge through the field-discharge resistance (a special resistance being fitted for this purpose).

Before opening the field switches of generators, the self-exciting switches, throw the field rheostat to "Low" and open when voltmeter stops moving towards zero.

In double-throw switches fiber blocks are furnished to slip in the clips of the switch not being used. These should always be placed in position.

Care and Management of Search-Lights.

To Place Lamp in Projector.—See that the clutch securing the barrel in position as to elevation is caught and then take off the front door. Do not leave this against anything but place it immediately in its own box for safe keeping. The magnet piece supporting the two shutters of the obturator is turned up to allow the lamp to pass under. Place the back end of the lamp on the slide and holding the front end up push the lamp in until it falls into the slot in the slides and then lower the front end. Push the lamp in until the focusing screw is engaged, and then the lamp can be moved with the wrench supplied for that purpose. Do not lift the lamp by the carbon carriers but by the body of the lamp. After the lamp is placed turn down the magnet piece.

To Place the Carbons.—Separate the carbon carriers by means of the socket wrench as far as possible. First, place the negative carbon, the one towards the mirror, with the end even with the carbon clamp and set up on the contact screw. Next place the positive carbon with the point about $\frac{1}{4}$ inch from the negative carbon and the end projecting through the clamp; then set up on the contact screw. Bring the points opposite each other by means

of the vertical and horizontal tangent adjusting screws. Before turning on the current, the points should be brought within ¼ inch of one another and the feeding screws should be turned to see that they work freely.

Operating.—The one in charge during operation should never leave the projector, but should constantly watch the burning of the carbons and the focusing of the lamp. If the crater is not burning in the center, the positive carbon must be changed by the vertical and horizontal screws and the arc drawn to the center. This is done by a wooden-handled socket tool through the side sliding door.

If from any cause the lamp feeds until the carbons touch they must be drawn apart by hand, using the crank-handle wrench provided for the purpose.

If mushrooms form on the negative carbon they must be broken as soon as possible (when the neck gets small), and this can be done by moving the positive carbon quickly up and down, striking the mushroom and breaking it off.

Do not keep the beam of light higher than 40 degrees above the horizontal for any length of time, as pieces of incandescent carbon may fall on the mirror and break it.

Focusing.—This is done by the focusing screw by which the lamp is moved nearer to or further away from the mirror. The most satisfactory focus is found when the beam of light is thrown with minimum divergency. If the beam is diverging the lamp must be moved away from the mirror, if converging it must be moved nearer the mirror.

Extinguishing.—Before turning off main switch, see that all projector doors are closed. This is to prevent cold air from getting inside the projector as it might crack the hot mirror. After the lamp is extinguished and cooled, it should be cleaned free from dirt and carbon dust. Brush the dust from the lamp with the brush furnished and do not blow it off, and see that it does not fall into the mechanism. Dust mirror with dry rag and polish with chamois skin. Do not expose mirror to direct rays of the sun.

The only parts of the lamp requiring oil are the feeding screws and pivots of feeding armature, for which clock oil should be used, and this very sparingly.

Care of Night-Signal Set.

Most of the troubles of the night-signaling apparatus arise in the cable leading from the keyboard to the lanterns, as this is exposed constantly to the weather and to the heat and gases from the smoke pipes. The keyboard is made water-tight and can be installed under cover and it ordinarily gives no trouble, if kept clean and is handled with care. The plug on the cable end which carries the contact points for the leading wires can only be inserted in one position as the receptacle has a pin which engages a slot in the plug. There is a nut on the end of the plug which should be screwed tightly against the soft-rubber packing after the plug is inserted. It is a good plan when the plug is well home and there is no necessity for its removal to serve the whole plug with small stuff and cover it with painted canvas to help keep out water from the contact points.

Another detail requiring attention is the soft-rubber packing used about the couplings and the rubber gaskets at the lanterns through which the cable leads. These are apt to become hard and dry, allowing water to get in to the lamp connections. They should be watched and replaced when necessary and the whole gasket and gland should be well taped over.

The cable can be renewed, one conductor at a time, if any should have become burnt out or rotted due to moisture and heat. The only trouble in renewing a conductor comes in making the connection to the plug. This is in three parts, the upper part screwing into the middle and the middle into the lower containing the contacts. The upper part can be unscrewed and pushed up along the cable without any trouble. The middle part can be unscrewed after coming up a set screw, and the gasket for the whole sixteen cables must then be worked along the conductors so the middle part can be drawn from the lower to get at the contacts. When this is accomplished the old conductor can be unsoldered and the new one soldered in its place and then passed through the proper hole in the gasket and through the other two parts, which can then be assembled.

From time to time the whole cable should be treated with some form of tar, as ship's rigging is, for protection against rain.

Care of Truck Lights.

As in the case of the night-signal set, most of the trouble comes in the cable. Particular attention should be paid to the receptacles for the cables to see that they are at all times thoroughly water-tight. The stuffing-boxes on the lanterns should be screwed down hard on the gasket and the whole thing, stuffing-box, gasket and all, should be thoroughly taped. After a long time the contacts in the controller may get discolored and burnt and the cover should be taken off at intervals and the contacts brightened up.

Care of Diving Lantern.

The main care of this is, of course, to keep it water-tight. The cable is brought out from the lamp terminals through a metal cap through a water-tight gland packed with a soft-rubber gasket passing through the handle of the lantern. On each end of the lantern is a metal cap, the joint between the metal cap and the glass being packed with a soft rubber.

A lamp can easily be replaced by removing the side rods which bind the two caps together, when the whole lantern comes apart easily. It is advisable to take the lantern apart frequently for the purpose of renewing the washers as they tend to vulcanize under the hard pressure. The cable gasket should also be frequently renewed.

When the lamp is used under water, moisture will be deposited on the inside of the lantern and this can be drawn out by unscrewing a large-headed screw tapped into one of the metal heads. When the moisture is removed the screw should be set tight, and a rubber washer placed between the screw-head and the cap.

Care of Connection Boxes.

Most of the trouble in the cables for the various battery and generator circuits for interior communication occurs in the connection boxes, through dampness. The connection to the connection boxes, whether from conduit or from molding, is made water-tight by a gland and a soft-rubber gasket. The boxes have water-tight covers with wing nuts and the covers should always be set up tightly.

Oxidation of the terminals is apt to occur, forming verdigris, which should be at once removed. The cover gasket and conduit gasket should be examined periodically and renewed if necessary. If moisture is found in a box it should be thoroughly dried before the cover is replaced.

Care of Appliances.

The greatest care should always be taken to see that thorough water-tightness is preserved throughout the whole wiring system. The glands of stuffing tubes through bulkheads and decks should be occasionally examined, and if necessary the packing renewed and the glands set up tight. The covers of all junction boxes and water-tight boxes of every description should be always screwed down tight on the rubber gaskets and the screw caps set up tight. The chains to the caps should always be intact, so there is no possibility of the caps becoming mislaid. Especially should this be the case with switches which require the removal of the cap before the switch can be turned. After using such a switch, the cap should at once be replaced. After using a receptacle, it is most necessary to see that the cap is replaced to avoid risks of short circuit and to keep out moisture. The caps of water-tight accessories should never be removed unless in case of necessity. Curiosity is not a sufficient necessity. The covers of most boxes are finished in a dull black and these should be occasionally wiped off with a clean rag slightly oiled to remove any traces of oxidation or verdigris. They should not be painted.

Fuse boxes should be looked at occasionally to see that only proper fuses are used. This is frequently necessary in the fire-rooms, where firemen have a habit of replacing burnt fuses by nails or pieces of wire.

When canvas covers are fitted, they should be kept on habitually when appliances are not in use or when they are not required to be off for inspection. Covers should be kept in proper condition and should be water-tight for those exposed to the weather, as for search-lights, telegraphs and indicators, etc. These covers should be removed and replaced by the dynamo-room force.

Care of Fixtures.

All fixtures are either silver-plated or bronze, and the bronze fixtures can be kept clean by wiping with a clean rag slightly oiled, but the oil should be wiped dry. Permanent fixtures usually do not require much attention, but movable ones are apt to show oxidation due to the handling they get from the moisture of the hands. It is not advisable to use polish on the silver-plated fixtures as most polishes contain acids which attack the plating. A dry powder may give a polish with good effect if used properly and sparingly.

The globes of all ceiling fixtures should be removed at times and wiped clean and dry, both on the inside and outside. Dust is bound to collect in these globes. If occasion requires it, they can be washed with hot water and soap, but must be thoroughly dried. The globes of steam-tight globe fixtures should be removed at intervals and cleaned and polished with clean waste. Incandescent lamps should be thoroughly clean on the outside, and opal shades should be kept free from dust.

Undoubtedly the greatest sources of grounds on lighting circuits come from the use of portable fixtures, and the greatest care must be taken with these, and any fault at once repaired. This is particularly true of deck lanterns and portables used in the fire and engine-rooms, subject to moisture or to great heat. All portables should be periodically overhauled to see that the connection to the fixture is water-tight, and that the receptacle plug is properly wired and free from short circuits. The conductors used with portables in coal bunkers or fire-rooms frequently break down in their insulation, being left to rest on hot ashes, or covered with coal that tears off the braid.

Care of Store-Rooms.

Nothing indicates the general condition of an electrical plant better than the orderliness and cleanliness of the store-rooms for electrical supplies. The room should be provided with proper lockers, shelves and drawers, and it is a good plan to mark with name plates what the various compartments contain, so in case anything is needed in a hurry, it can be found without overhauling a lot of unnecessary articles. Lamps are kept in specially-prepared

shelves and the different candle-powers should be grouped together. Wires should be kept on reels, properly marked with the number of feet and its size. Small wires can be kept in coils, hung up overhead. All small articles such as screws should be assorted in sizes and kept in appropriate boxes, and interior fittings should be laid out flat and neatly arranged. Care should be taken with these to see that the porcelain bases are not broken or chipped.

Portable fixtures, such as signal lanters, battle and deck lanterns, have their conductors coiled up neatly around them and hung on hooks from overhead. It is a good plan to tag them with the color of the lenses and the length of conductor they are fitted with.

Special care should be taken with breakables, such as globes, shades, spare lenses, spare screens, and it is a good plan to keep them packed in excelsior and in a separate locked compartment.

Spare conduit or molding can usually be kept overhead along the beams, and elbows or bends can be kept in barrels or laid out on shelves.

All instruments should be kept in their individual cases and kept locked if fitted to do so.

As far as possible the floor space should be kept free to allow as much space as possible for moving around and handling stores. A certain amount of small stores will necessarily be kept in the dynamo-room, but only such articles that are needed in a hurry, and all others should be kept under lock in the store-rooms. No one but those authorized to do so should ever be allowed to take articles from the store-rooms, for in this way only can a proper expenditure be kept.

Spare armatures should not be allowed to rest on the deck, but should rather be mounted on a shaft raised from the deck, and turned now and then. They should be properly wrapped to prevent injury and covered entirely to keep out dust and dirt. Spare parts of engine should be kept together, coated with tallow and white lead.

CHAPTER XXXVI.

PRINCIPLES OF WIRELESS TELEGRAPHY.

PART I.

DEFINITIONS.

An **alternating current** is one that periodically reverses its direction in its circuit, flowing first in one direction and then in the other. This alternating current is due to an alternating E. M. F., that gradually increases from zero to a positive maximum then decreases to zero, and then reverses its sign, increases to a negative maximum and then decreases to zero.

The greatest positive or negative values of the alternating current is called the **amplitude** of the alternations.

Each complete set of operations is called a **cycle.**

The time that elapses between the commencement of the current in one direction and its beginning again in the same direction is called **a period.**

The number of periods per second is called the **frequency** of the alternations.

A **high frequency alternating current** is one in which the frequency is reckoned in thousands, and, for convenience, if the frequency is above 1000, such an alternating current is said to be of high frequency and below that number it is said to be of low frequency.

An **electric oscillation** is defined to be an alternating current whose frequency is reckoned in the hundreds of thousands, the amplitude of each alternation being less than the preceding one.

Sustained oscillations are those in which the alternations are very rapid and do not lessen in their amplitude.

Damped oscillations are those consisting of a limited number of alternations, the amplitude of each of which is continually decreasing.

Under damped oscillations, if the lessening of the amplitude is

very rapid, they are called **strongly damped** oscillations, and if it is slow, they are called **feebly damped** oscillations.

Capacity.

All conductors have capacity, depending on their form and size.

The capacity of a conductor is greatly increased when it is placed near a conductor electrified with the opposite kind of charge, so therefore a greater quantity of electricity may be put into it before it is charged to an equal degree of potential.

An arrangement for holding a large quantity of electrification is called a condenser.

The capacity of a condenser depends upon:

1. The size and form of the conductors, usually metal plates or coatings.

2. The distance between the conductors.

3. The capacity of the material (dielectric) separating the conductors.

The dielectric separating the conductors must be of necessity a non-conductor, the usual form being either glass, air, mica, or oiled paper.

The effect of introducing a condenser into a circuit carrying a continuous current is to completely stop the current, as the dielectric is a non-conductor, but on introducing it into an alternating current, the effect is different. The alternating current simply passes into and out of the condenser, changing its sign, as the current charges it first positively and then negatively. The effect is to hold back the current from the E. M. F. impressed in the circuit, and the current is said to *lead* the E. M. F.

The total charge in a condenser depends on its potential and its capacity, and the potential depends on the source of electricity to which it is connected, and by which it is charged.

The practical unit of capacity is the **farad**, and is equal to 10^9 of the absolute unit of capacity, and is the capacity of a condenser that will be charged to a potential of 1 volt by 1 coulomb. The **microfarad** is one-millionth of a farad, or $\frac{1}{1{,}000{,}000} \times \frac{1}{1{,}000{,}000{,}000} = 10^{-15}$ absolute units. The capacity of all condensers is stated in microfarads.

Induction.

The phenomenon of induction has been explained in previous chapters, and it has been shown how currents are induced in conductors when they are moving in a magnetic field, or when there is any relative change in the number of lines of force cut by the conductor.

If the magnetic field surrounding a conductor carrying a current is changed due to changes in the current itself, there is induction produced which reacts on the current producing the change in the field. This is not marked in a straight conductor but if it is coiled into a spiral the magnetic field due to each coil reacts on the others and produces greater changes in the flow of current, and the effect is still more marked if the coils are wound on a core of iron.

This phenomenon of **self-induction** acts to oppose changes in the current; that is, if the current is increased, self-induction opposes the increase, and if decreased, it opposes the decrease.

The total amount of cutting of lines of force by a circuit when a current of 1 ampere is turned on or off in it is called the **inductance** of the circuit and is denoted by the letter L, and is numerically equal to

$$L = \frac{S \times N}{C}$$

where S = number of turns in a coil,
N = number of lines of force due to C,
C = current in amperes.

The practical unit of induction is called the **henry** and corresponds to a cutting of 10^9 lines of force when 1 ampere is turned on or off.

As self-induction resists changes in the flow of current, its effects are strongly manifested in currents of constantly changing flow (alternating currents). The resistance of a conductor due alone to changes of current is called its **reactance.**

The combined effect of the resistance (ohmic) and the reactance is called the **impedance.**

The effect of introducing inductance in an alternating circuit is to cause the current to *lag* behind the impressed E. M. F. and thus capacity and inductance produce opposite effects.

PART II.

PRODUCTION OF HIGH FREQUENCY OSCILLATIONS.

A necessary feature of wireless telegraphy requires the production of high frequency electrical oscillations, and this necessity will be shown when the operation of conveying the electrical energy from one point to another is considered.

The electrical discharges necessary to the formation of electric oscillations may be produced by an ordinary Leyden jar, by a condenser, by an induction coil, or by a combination of any of these. The discharge from any of these electrical contrivances may be continuous, intermittent, or oscillatory. The discharge of a Leyden jar or a simple condenser appears to be practically instantaneous, but as a matter of fact, experiment shows that usually it is oscillatory, the period of oscillation being so short that the discharge appears as a single spark. If the discharging circuit could be made without resistance, it is likely a Leyden jar would exhibit a discharge that would oscillate backwards and forwards from one coating to another, the difference in potential between the two coatings becoming less and less, finally arriving at a common zero potential.

The effect of introducing resistance is to choke down the oscillatory discharge, a discharge through a high resistance giving a series of strongly damped oscillations which soon dies away.

Production of Electric Oscillations by the Discharge of a Condenser.—If the two conductors of a condenser are brought to different potentials and they are suddenly connected through a conductor having inductance but small resistance, experiment shows that the equalization of their potentials takes place by means of a discharge consisting of a series of damped electrical oscillations.

There are many mechanical analogues that may be used to show the similarity of damped oscillations, a common one being a simple pendulum. When the pendulum is hanging up and down and motionless there is the force of gravity acting on its bob, but no turning moment, as the arm is zero. As the bob is drawn from the vertical and held at some point, there is now a turning moment tending to return it to its original state of rest. This is the pro-

duct of the force of gravity multiplied by the horizontal distance it has been displaced. The difference between the two forces in the two cases corresponds to the difference of potential in the case of the conductors of the condenser. When the bob is released, it passes through its zero position and swings to the other side, due to the inertia of the mass of the bob. The distance it will be displaced on the opposite side is less than the distance it was on the first, and when again at rest, it swings back, passes through zero and again to the first side with decreased swing. This action goes on with continually decreasing swing until brought to rest. All the distances on one side correspond to positive potential, those on the other to negative, and they are gradually brought to a neutral or zero potential when the bob is at rest.

The necessary conditions for the creation of mechanical oscillations are that the thing moved must tend to go back to its original position when the restraining force is withdrawn and must have sufficient inertia to overshoot the position of equilibrium in so doing.

In the same way the necessary condition for establishing electrical oscillations in a circuit is that it must connect two bodies having capacity with respect to one another and the circuit must possess inductance and low resistance.

Fundamental Equation of Wireless Telegraphy.—The electrical factors controlling the discharge of a condenser are the ohmic resistance of the circuit, the capacity and inductance in the circuit.

If R = resistance in ohms of the circuit,
K = capacity in farads,
L = induction in henries,

then if $R > \sqrt{\frac{4L}{K}}$ there will be no oscillations in the electrical discharge, but if

$$R < \sqrt{\frac{4L}{K}}$$

there will be oscillations.

In the latter case, if the number of oscillations is n the oscillations will be such that

$$2\pi n = \sqrt{\frac{1}{KL} - \frac{R^2}{4L^2}}.$$

If R is small,

$$n = \frac{1}{2\pi\sqrt{KL}}, \text{ or}$$

the circuit vibrates in its natural period equal to

$$T = 2\pi\sqrt{KL}.$$

Apparatus for the Production of Intermittent Damped Oscillations.—The usual method employed for the production of electric oscillations is the discharge of a condenser of some kind, the charge and discharge being repeated at regular intervals.

The connections of the apparatus are shown in Fig. 382.

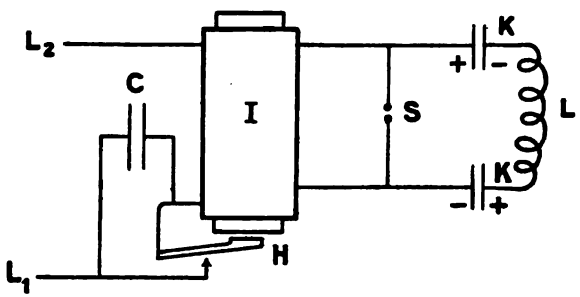


FIG. 382.—Elementary Sending Circuit.

I shows an induction coil, whose primary terminals are connected to the source of supply of electric current marked L_1 and L_2. One plate of each of the condensers K is connected to the terminals of the secondary coil and the other plates are connected in series by the inductance coil L. The terminals of the secondary coil are also connected by the spark gap S.

When current is sent through the primary coil of the induction coil, at each interruption by the hammer H, an E. M. F. is created in the secondary coil. This charges the condensers, the plates connected with the secondary with opposite charges, and those connected with the inductance L of opposite charges, and also opposite to the other plates. The first result of interrupting the primary may be then as represented in the figure by the algebraic signs.

When the spark balls S are a suitable distance apart, the con-

densers being fully charged, the difference of potential between the plates of each breaks down the insulation of the air between the spark balls and the charged condensers discharge themselves through the spark gap, the outer plates neutralizing themselves through the inductance L, setting up oscillatory discharges in this coil and it is then said to vibrate electrically.

Electrical Vibration of the Inductance.—It has been shown above that the natural vibration period of the circuit containing the inductance depends upon both the induction and capacity of the inductance coil and is numerically equal to $2\pi\sqrt{KL}$.

Just before the condensers discharge themselves, the total energy is all electric, and at the instant that discharge takes place, the opposite charges move towards each other in the inductance. During this act of neutralization of potential, a magnetic field is set up around the coil, and at the instant of neutralization, all the electric energy has been converted into magnetic energy. The strength of this magnetic field depends on the amount of the moving charges and on the inductance of the conductor.

If there has been but one charging of the condensers, there will be but one discharge, and the magnetic field set up around the inductance having no continuous source of supply, will collapse on the coil, and the magnetic energy will be converted into electric energy, charging again the condensers, but with a less charge than before, due to the energy lost in heating the wires. The phenomenon is then repeated, the energy being first electric, then magnetic, and so on until the charges are fully neutralized.

If there is a continuous source of supply of E. M. F. and the condensers are being continually charged and discharged through the spark gap and the inductance coil the magnetic field induced around the inductance coil cannot collapse on the coil as other fresh fields are continually being set up, and as a consequence the magnetic field radiates off into space, producing the so-called electric waves.

Senders.

The purpose of all senders is to produce high frequency electric oscillations. The general method of producing these oscillations has been illustrated in Fig. 382, but a more general method, illus-

trating practically all the principles of wireless transmitters is shown in Fig. 383, known as the Tesla apparatus.

In this elementary figure are represented all the elements of transmitters for the production of high frequency electric oscillations. The elements are made up as follows:

L_1L_2 = lines for the supply of E. M. F.
I' = primary of the induction coil.
I'' = secondary of the induction coil.
CC = choking coils to extinguish the arc at the spark gap.
S = discharge spark gap.
K = condenser.
L = inductance.
I''' = primary of oscillation transformer (air core).
I^{IV} = secondary of oscillation transfer.
S' = discharge spark gap of oscillation transformer.

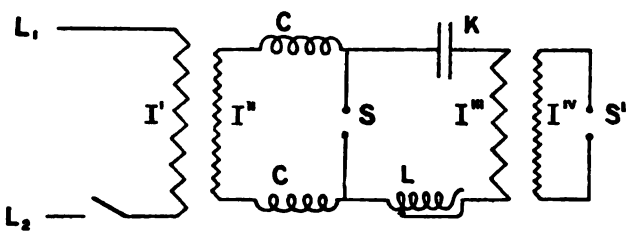


FIG. 383.—Complete Typical Sending Circuit.

Arc Stoppers.—Due to the alternating current produced in the secondary coil of the induction coil, there is a tendency to the production of an arc across the spark gap which would lessen the production of oscillations, and the choking coils CC are introduced to prevent this, and with the spark balls a suitable distance apart, the only spark that will pass will be that due to the discharge of the condenser.

Oscillation Transformer.—The primary circuit of this transformer I''' is placed in series with the condenser and spark gap, and this constitutes the circuit in which the electric oscillations are set up by the discharge of the condenser. These oscillations act inductively on the secondary coil, and if this coil has a larger num-

ber of turns than the primary the difference of potential at its terminals will be greater than in the primary by the ratio of the capacities.

When the primary circuit I' is excited, high potential high frequency oscillatory sparks will pass between the spark gap S'.

The other elements of this circuit have been previously described.

Practical Apparatus for the Production of Damped Oscillations. The elements necessary for the production of intermittent damped oscillations have been shown in Figs. 382 and 383.

Though an induction coil is shown as the means of producing high electromotive force, any other type of generator of high electromotive force might be used. In the majority of practical apparatus, the induction coil, the primary of which is excited by an interrupted continuous current, or alternating current, either direct or produced by some sort of transformer is used.

The construction of an induction coil suitable for wireless use has been described in Chapter VIII.

An ordinary induction coil can be employed as an alternating current transformer by removing its interrupter attachment and supplying the primary direct with the alternating current. For use on shipboard where alternating currents are not available it is usual to make use of a motor-generator, the motor end being wound for continuous current from the constant potential mains and directly connected to an alternating current armature, this arrangement transforming the low potential of continuous current into potential of alternating current. This alternating current is then supplied direct to the primary, and in the form of induction coils generally used, a potential of 20,000 to 30,000 volts can be obtained from the condensers.

If the continuous current is used, the use of some form of interrupter is necessary. These are generally of one of the following classes: **hammer, dipper, motor turbine,** or **jet,** and **electrolytic interrupters.**

Although all these present peculiarities, the one in general use is the turbine or mercury jet interrupter. In this a jet of mercury is

forced out of a small aperture against a metal plate, and the jet is interrupted by means of a toothed wheel, rotated by a motor, which also works a centrifugal pump by which the mercury is squirted. In another form a jet of mercury is thrown on a metal plate and is made intermittent by revolving the plate, the current passing through the mercury. The mercury is covered with oil or alcohol to prevent oxidation. The length of the revolving plates or segments as well as their speed can be varied and so the number of interruptions is well under control.

Electrolytic interrupters present marked peculiarities, in which an electrolytic cell of dilute sulphuric acid as the electrolyte and electrodes of lead and platinum are used. Under certain conditions of E. M. F., current passed through this cell will interrupt the circuit periodically and an enormous number of interruptions can be made.

Condensers.—A condenser in its most general form consists of a pair of conducting surfaces separated by a dielectric. Glass, mica, or micanite, and ebonite are about the only solid dielectrics suitable for condenser construction.

A condenser in ordinary use is the Leyden jar, being a glass jar coated inside and outside with tin foil, the tin foil secured to the glass with a thin shellac varnish. These jars are made in various sizes, and as usually made will stand charging to about 20,000 volts. They are arranged to be connected in series or parallel. The inside coating of each jar is connected by some positive form of connection to a terminal leading through the top of the jar and to connect in parallel, all these terminals are connected together and the outside coatings are connected by the jars resting on a common connecting plate.

Plate Form.—Another form of condenser is constructed by covering flat sheets of flint glass with tin foil on both sides, leaving a margin of glass all around with the exception of a small strip on each side which is allowed to project over the edge of the glass, this projection on each side being on opposite corners of the plate. A number of plates are made this way and are then built up, laying them back to back and front to front, so the corresponding terminal strips on each will coincide, and they are secured together, and all the strips of each are connected to common terminal contacts.

Variable Condensers.—Where variable small capacities are required they are made with flat plates with air dielectric, the plates arranged so they can be moved to or from each other.

In another form, a number of fixed pairs of quadrant-shaped plates of brass are placed one above the other in an ebonite box, and all are connected together and to one terminal on the box. In the center is a pivotted vertical rod carrying a number of brass plates which are spaced apart the same distance as the fixed plates. The arrangement is such that every other plate is a fixed one, and

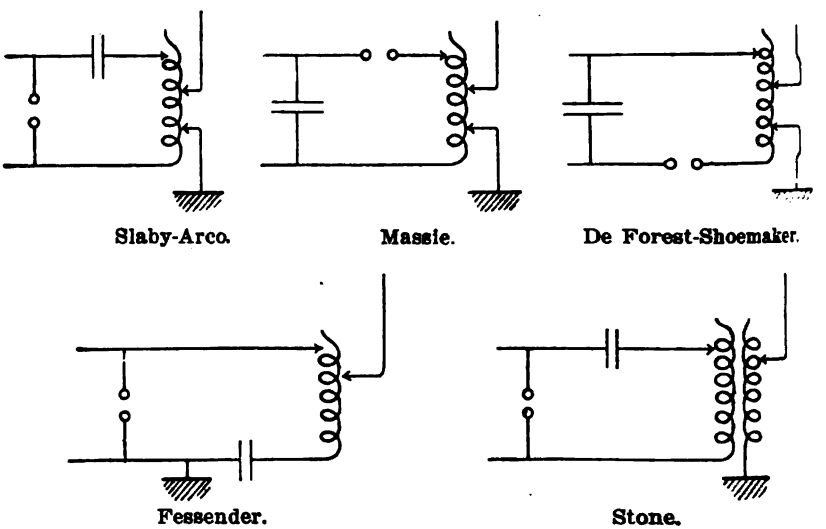


FIG. 384.—Sending Circuits.

every other one a movable one. When the movable plates are turned so as to be directly under the fixed ones, they act as condenser plates, and when turned away they vary the capacity. The dielectric can be air or the plates can be immersed in some form of insulating oil.

There are several other forms of variable condensers used, made on the step-by-step principle or of the sliding type. The former have a definite number of capacities depending on the number of steps, while the latter has any number of capacities between the maximum and minimum values.

Inductances.—Variable inductances for transmitting circuits are almost invariably made on the sliding principle. The variable inductance usually consists of large, bare wire wound in a helix on an insulating frame, with the turns widely separated and fitted with sliders by which more or less turns can be connected to the circuit. Other sliders are provided by which more or less turns can be connected between the aerial and ground.

Sending Circuits.

The following elementary diagrams show the sending circuits of the various forms of wireless sets used on ships of the Navy, and it will be seen that they all conform to the general principles as illustrated in Fig. 384, the differences being in minor changes in the arrangement of the essential parts.

In each case, the lines leading from the left are connections from the secondary coils of the induction coil.

These are all *direct*-connected sets with the exception of the Stone, which is an example of *inductively* connected aerial.

PART III.

ELECTROMAGNETIC WAVES.

The energy of the sending instrument is conveyed to the receiving instrument through the atmosphere, practically, or at least theoretically, through the all-pervading ether that permeates all space and bodies. The present accepted theory regarding the transmission of electricity is that it is due to a series of whirls or streams of bodily movements in the ether, and the energy is conveyed from one point to another by vibrations of the ether particles, in a manner similar to that in which light is propagated. Just as a luminous body sets up vibrations in the ether, so do electrical oscillations when rapid enough cause bodily motion of the substance of the ether, these movements taking the form of waves that travel through space with the same velocity as light. These undulations are partly electrical and partly magnetic, the vibrations causing each being at right angles to each other and both are at right angles to the direction of the propagation of the waves. The movement of

the ether particles is restricted to extremely small ranges of distance, the wave form travelling on as in the case of water waves, where the particles of water simply vibrate up and down.

It has been shown by experiment that these electrical waves have many of the properties of light waves and can be reflected, refracted, and polarized. They also have the property of passing unchanged through brick, stone, or woodwork and through many substances that are opaque to light.

Properties of Electric Waves.

Considering an ordinary wave as produced by simple harmonic motions of the particles of ether, each particle vibrating in its own plane at right angles to the onward direction of the wave and each particle differing in phase by a certain definite ratio from another, the onward form of the wave in a single plane would have the shape of the curve of sines.

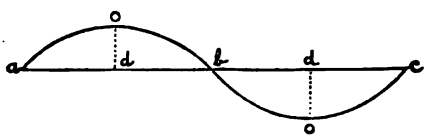


FIG. 385.—Wave Form.

In the wave form shown in Fig. 385, the distance *od* is called the *amplitude,* being equal to the greatest displacement of the particles from their normal position along the line *ac.* The *wave length* is the distance *ac,* and at *c* all the particles are in the same relative phase as at *a.*

The *period* is the interval of time which is taken by the particles in passing through all the relative phases from *a* to *c,* or at the end of one period, all the particles are in the same relative phase as at starting. The period of the wave length determines its *frequency,* the shorter the period, the greater the frequency and vice versa. The number of waves that pass a given point in a certain interval multiplied by the length of one wave gives the total distance travelled by the waves in the given interval, and if that interval be unity, the distance travelled becomes the speed or velocity of the propagation.

The amplitude of the waves depends upon the energy of the electrical discharge producing the waves, just as the amplitude of sound waves caused by a vibrating string depends upon the energy with which the string is plucked. The number of vibrations depends upon the electrical characteristics regulating the discharge, independent of the energy, in the same way that the pitch of sound, or the number of vibrations, produced by a vibrating string is dependent upon its length and independent of the energy setting it in vibration.

If $v =$ velocity of propagation,
$\lambda =$ the wave of length,
$n =$ the number of vibrations,
then $v = n\lambda$.

As the velocity of light waves and electrical waves, according to the accepted theory which has been well verified by experiment, is equal, it follows that the number of electrical waves multiplied by the length of one wave must be equal to the velocity of light.

Experiment shows that the length of electrical waves compared to those of light waves is very long, so the frequency of these waves compared to light waves must be very low. While the frequency of light vibrations is measured in the trillions per second that of the lowest producing the sensation of light being about 392 trillions, those of electrical waves are more often in the thousands. The greatest frequency obtained with electrical waves is about 50 billions per second, which would give a wave length of about 6 millimeters. Frequencies as low as 500 per second have been obtained. The wave length used in wireless telegraphy varies between 100 and 1000 meters, being limited, as later shown, by physical considerations.

The wave length and frequency necessarily depend upon the same characteristics, and a change that will vary one will vary the other. The wave length produced by an organ pipe when blown depends upon the length of the pipe, and similarly it may be said that the wave length of an electrical discharge depends upon the "electrical size" of the apparatus that furnishes the discharge.

The analogy of sound waves in an organ pipe to the electric waves transmitted along a conductor may be carried still further, experi-

ment showing that the nodes and loops of the sound waves find their counterpart in electric waves. Referring again to the form of the wave, the points *a*, *b*, and *c* represent the nodes or points of no vibration, or rather points at which the resultant of all the vibrations is zero, and 0.0 loops, points representing the position of maximum vibration, or where the particles have the freest motion; and in the electric waves, the points of greatest potential. At the nodes, in the electrical waves, there is the least potential.

An organ pipe closed at one end, when blown, gives as its fundamental note, a sound represented by a wave such that there is a loop at the blown or free end, and a node at the other, the closed end. This is shown in Fig. 386, where the dotted line shows the form of the wave.

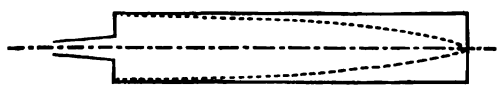


FIG. 386.

In this wave, the amplitude varies from nothing at the closed end to a maximum at the open end, and it depends upon the energy expended in forcing the air into the pipe. The wave length, however, and consequently the frequency depends on the length of the pipe, whether the force of the air be strong or feeble. The amplitude produced by a single strong puff of air, might be obtained by a series of more feeble puffs constantly directed into the tube, if these feeble puffs are rightly timed with each other.

If a conductor with one end insulated while the other end is kept at a constant potential by being connected to earth, is free to vibrate electrically, under the action of an electric force, it is found that there is a node of zero potential at the earthed end and a loop of maximum potential at the free end, while the wave length will depend upon the length and capacity of the conductor. From the nature of the phenomenon producing electric vibrations, it is not possible to obtain a single electric blow sufficient to produce the required amplitude, and recourse must be had to a series of light blows well timed with each other and to the natural frequency of the conductor to produce the desired result, as in the case of the light puffs of air properly timed in the organ pipe.

It is noted that the full wave length as shown in Fig. 386 would be four times the length of the pipe, and so in the case of the electrical oscillating conductor, the length of the conductor is theoretically one-fourth of the wave-length produced.

Aerials.

An aerial wire or **antenna** is a name given to the conductor by which the electrical oscillations are directed into the ether of the atmosphere and is the essential element in all wireless telegraphy.

If in Fig. 383, the balls of the spark gap S' are lengthened out so that the high frequency oscillatory sparks cannot pass between them, the circuit will nevertheless still continue to vibrate electrically, setting up magnetic fields around it when the induced current is alternating back and forth due to the inductive influence of the primary coil I''', and throwing off into space the electromagnetic waves, if the source of power is being put at intervals into the primary coils I'.

If the lower ball of the spark gap S' is bent around and connected to earth, and the upper ball bent around and lengthened vertically, we shall have the aerial as universally used for wireless telegraphy, the aerial still vibrating electrically, with the lower end earthed and the upper end free.

The action of the electrical vibration, or the induced alternating current, in the earthed aerial may be best illustrated by considering the spark gap S as being directly in the aerial.

FIG. 387.—Wave on Earthed Aerial.

Fig. 387 shows such a case. If now the two sides of the spark gap are connected to the opposite plates of a condenser, the upper part is charged to a high potential and the lower part to zero potential, that of the earth, and discharge takes place across the gap. Just before discharge takes place the upper portion of the aerial has a certain capacity with regard to the earth and takes a certain charge, and as the spark has a low resistance, the discharge is oscillatory, but much damped, as the energy is rapidly radiated.

The earthed end of the aerial is at zero potential, or there is

a node of potential at that point. It then follows that there must be a loop of potential at the upper or free end, and the fundamental oscillation excited in the whole length of the wire is one in which the potential increases all the way up the wire from the earthed to the free end, and this wave form is shown by the dotted line in Fig. 387.

The distribution of the current is such that there is a maximum current at a potential node and minimum of current at a potential loop.

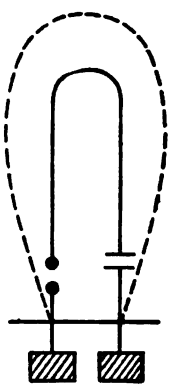


FIG. 388.
Looped Aerial.

The elementary form of the wave would indicate that the aerial should be one-fourth of the wave length of the oscillation. Owing, however, to the inductance in the aerial, experiment shows that the length is more nearly equal to one-fifth of the fundamental wave length.

It is not necessary that the aerial should be directly connected to the circuit containing the spark gap, but it can be connected inductively, as shown in Fig. 383 in the elementary transmitter, formed as stated, by bending the arms of the spark gap S' around, earthing one, and lengthening the other vertically.

Looped Aerials.—A looped aerial is one made in the form of a loop with its two ends connected to earth, one end through the spark gap and the other through a condenser, as illustrated in Fig. 388.

These are used in some forms of wireless sets, and present the peculiar circumstance that they will radiate for some frequencies of oscillation and not for others. If the lower condenser plate is not connected to earth, there is no radiation from the loop as a whole. Some characteristic forms of aerials are shown in Fig. 389.

Coupling.

Direct and Inductive Coupling.—Direct coupling consists in connecting the aerial directly to some point on the oscillating circuit, usually the inductance, another point on the inductance being connected to earth.

Inductive coupling consists in coupling the oscillating circuit to the aerial inductively, the secondary of the oscillating transformer being in series with the aerial.

These are illustrated in Figs. 390-391.

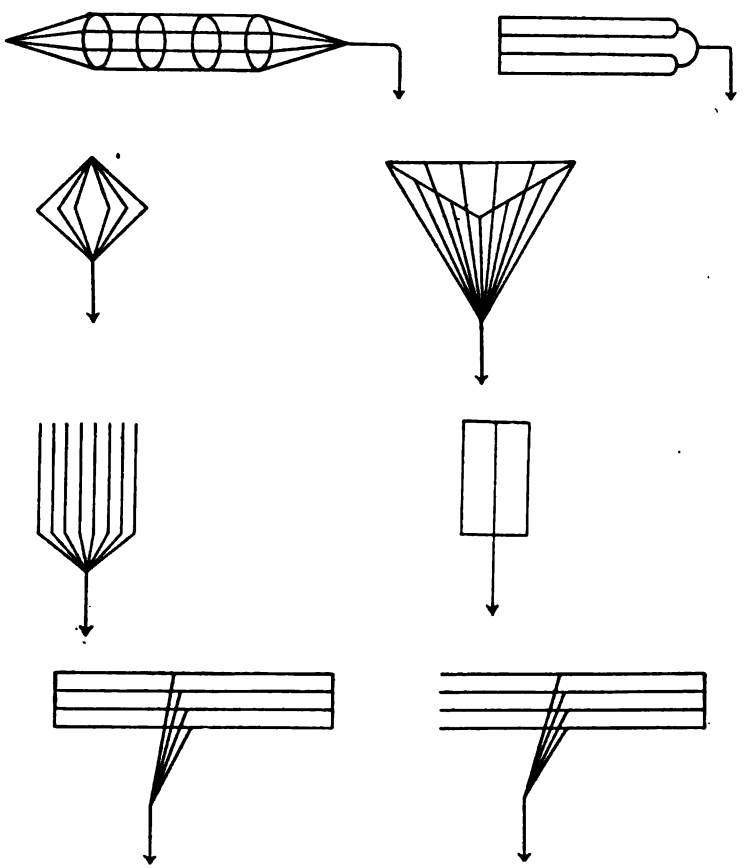


FIG. 389.—Typical Forms of Aerials.

Open and Closed Circuits.—The closed circuit is that part containing the spark gap, condensers and inductance, and the open circuit is that part containing the aerial with its portion of the inductance.

In direct coupling, the open and closed circuits have some turns of inductance in common, as the turns of the inductance embraced between the connections 1 and 2 in Fig. 390. When the common turns of the closed and open circuits in directed connected coupling are large in number, or the coils of the inductively connected circuits are close together, the circuits are said to have **a close** or **tight coupling.** In this case the energy is radiated very fast from the aerial and the oscillations are correspondingly damped. When the common turns of the closed and open circuits are few in number, or the inductively connected coils are few, the circuits are said to have a **loose coupling.** In this case, the oscillations are kept up more strongly and the radiation from the aerial is less.

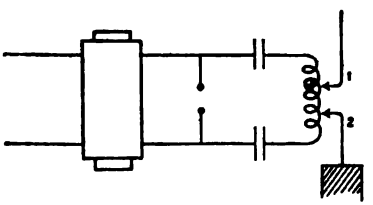


FIG. 390.—Direct Coupling.

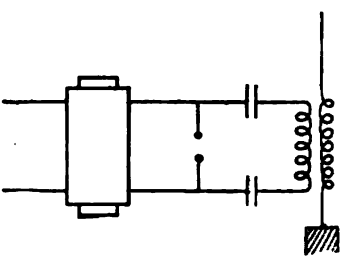


FIG. 391.—Inductive Coupling.

Each of the closed and open circuits has a natural period of vibration, due to its capacity and inductance, and when they are adjusted to have the same period of vibration, they are said to be in **tune** with one another.

Though each of the closed and open circuits may be tuned with each other before coupling, yet when they are coupled, the resulting period is not the same as either, and experiment shows that the resulting oscillation has two periods of vibration, and consequently two different wave lengths.

In close coupling, there results two periods of vibration, one longer and one shorter than the natural period of either circuit.

In loose coupling, the resulting two periods more nearly coincide with the natural period of each circuit.

The **percentage of coupling** is the ratio of the difference of the

periods of the two waves sent out to the natural period of each circuit; or what amounts to the same thing, the ratio of the difference in length of the two waves sent out to the natural wave length.

Detachment of Electromagnetic Waves.

Let Fig. 392 represent the aerial connected inductively to a closed oscillating circuit.

Just before discharge at the spark gap takes place, all the energy is stored in the condenser plates and is electrostatic. At the instant of discharge, the charges move towards one another as indi-

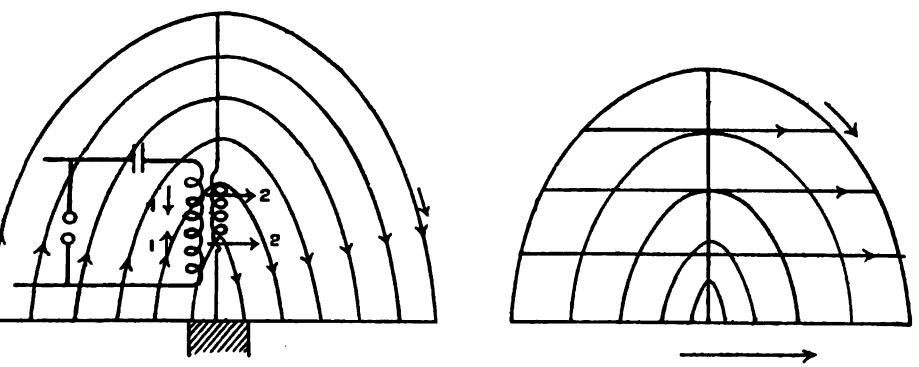


FIG. 392.—Detachment of Waves.

cated by the arrows, 1—1, and induce **magnetic** lines of force in the inductance of the aerial, whose direction is perpendicular to the direction of the aerial, as indicated by arrows 2—2. Due to the induction of these magnetic lines of force a current is induced in the aerial. These induced currents vary in intensity along the aerial and have the greatest value at the earthed end, as at this point it has been shown that the potential is least or the rate of change of current greatest, and have the least value at the top end of the aerial. This moving current or charge carries with it its **electric** lines of strain. There is a lateral pressure in the ether tending to keep these lines apart from one another and a tension along them tending to shorten them.

The result of one single discharge at the spark gap might then be graphically represented by the curved lines of electric force or electrostatic lines of strain as shown in the figure radiating off each side of the aerial. It must be remembered that this condition of electric stress is produced in all directions around the aerial, making a semispherical surface bounded by the furthest removed electrostatic line of force. Although this surface is represented as a spherical ring, it may not be so, the only condition being that it is a closed surface. The electrostatic lines are closed through the ground, being the result of the common potential.

The result shown is that at the instant after discharge. The reaction immediately follows; the lines of force, both electrostatic and magnetic collapse on the aerial, and if there are no more oscillations, the lines of force are dissipated, the electrostatic lines closing on themselves through the ground and being completely neutralized.

However, as the closed circuit is vibrating rapidly, the outward rushing of the second series of lines takes place before the first can entirely collapse and so pushes them, as it were, further along, and as they are not entirely collapsed the energy of the succeeding oscillation causes the electrostatic lines to be pushed further away. The magnetic lines are increasing at the same time. All matter possesses inertia and the collapsing lines of force cannot immediately return owing to the inertia of the imponderable ether.

Each succeeding oscillation along the aerial finds the electrostatic surface pushed further and further along until finally it is detached from the aerial and travels onward through space as a wave form with its two characteristic vibrations at right angles to each other. The wave is shown as a semispherical ring travelling along over the ground and directed by it. The lines of vibration of the ether particles producing electrostatic induction form meridians of this sphere or vertical circles and those producing electromagnetic induction are at right angles, and form circles of latitude, or horizontal concentric circles in a section of the ring.

These waves are propagated in all directions and the direction of propagation is at right angles to the directions of the two vibrations.

These waves maintain continuous contact with earth and are not

propagated throughout space and cannot be reflected by the earth into space as might be the case if they were completed on themselves independent of the earth. This earth connection also facilitates the transmission of the wave in a direction parallel to the earth's surface. The earth guides the waves, allowing them to follow its curvature and pass obstacles if they are not too large in proportion to the size of the wave. The dimensions of the wave increases with the height of the aerial and a big wave will more easily overcome a distant obstacle than a small one. The dimensions do not refer to the length or amplitude of the wave which depends respectively on the frequency of the oscillation of the aerial and on the energy of the sending apparatus, but to the volume, or it might be said, the mass of the waves. The longer the waves, the more easily they will flow around obstacles, so that on the other side the vibrations are still perceptible, and long wave length is a very desirable quality of these electromagnetic waves for successful wireless work.

PART IV.

RECEIVING CIRCUITS.

It has been shown that the wave surface detached from the aerial of a sending station proceeds through space as a continually increasing disturbed mass of ether in which there are two distinct lines of vibrations of the ether particles at right angles to each other. One set of lines of vibrations (magnetic) are practically parallel to and the other (electrostatic) are perpendicular to the earth's surface.

If an earthed conducting wire is held vertical to the earth's surface in a region where these waves are travelling the lines of force will direct themselves towards it in order to go to earth through it, and the higher the aerial the more lines of force it will be able to embrace. This conductor will be cut at right angles by the magnetic lines of force, which are proceeding as a series of horizontal concentric circles, and will induce alternating potentials in it. Similarly, a horizontal conductor will be cut by the electrostatic lines of force and alternating potentials would be induced in it. A conductor in any position between the vertical and horizontal

positions will be acted upon by the combined action of both series of lines of force.

If this receiving aerial has a natural period of vibration due to its capacity and inductance equal to that of the passing waves, the amplitude of induced currents will gradually rise, due to the successive impacts of each advancing vibration, the effect of each one being added to the preceding one.

The analogy of this is seen in the ringing of a heavy bell. On first drawing the bell rope, the bell may barely move, but a second pull rightly timed will cause an increased vibration and soon it may begin to swing in its own particular period of vibration, and each pull of the rope at the proper time will increase its swing until finally the bell rings. The bell then has been rung by a series of very light pulls, each correctly timed to correspond to the natural vibration period of the bell as it is suspended.

If the periods of the wave and the aerial are the same, each passing wave will add its potential to that due to the preceding one and the amplitude of the vibration will soon reach its maximum, when the aerial will radiate as much energy as it absorbs.

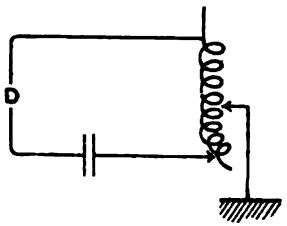
To increase the natural frequency of its vibrations, the aerial is either connected direct or inductively to a closed circuit in which there is both capacity and inductance and in which either may be varied.

The receiving circuit then is similar to the sending circuit, the place of the spark gap being taken by the detector, by which the vibrations of the closed circuit are made manifest.

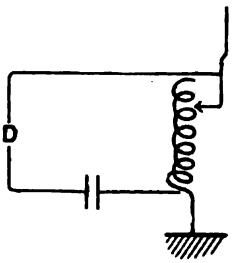
Whatever form of detector is used, it must be sensitive enough to respond to the maximum amplitude, or greatest potential, of the oscillating circuit.

The following elementary diagrams show the receiving circuits of various forms of wireless sets, and it is noticed they contain nothing but the aerial, inductance, and capacity in circuit with the detector, which in each case is marked *D*.

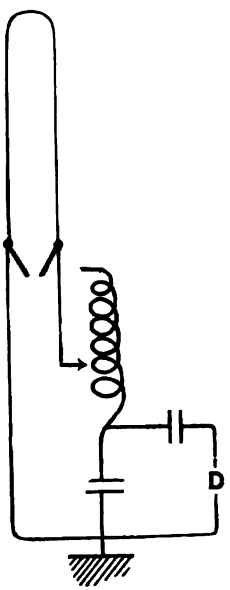
Some of these present peculiarities, notably the Stone, De Forest, and Shoemaker circuits. The circuit of the Stone system is inductively connected, and the middle circuit, as shown, is called a **weeding out** circuit. This is used to prevent interference when



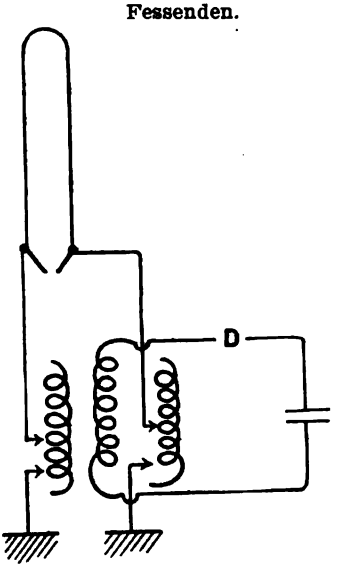
Slaby Arco Massie.



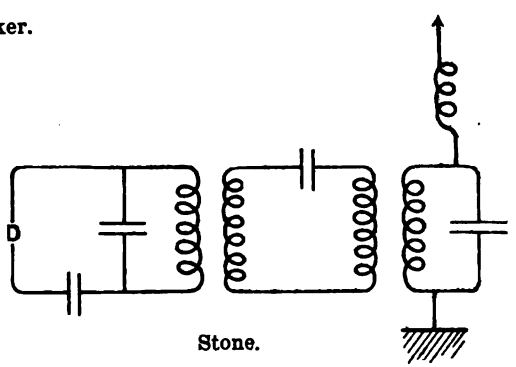
Fessenden.



Shoemaker.



De Forest.



Stone.

FIG. 393.—Receiving Circuits.

very close tuning is sought, but can be cut out wnen it is not necessary.

The De Forest and Shoemaker use the loop aerial, the controlling idea being the setting up of **stationary waves** in the closed circuit, which is grounded. By changing the relative positions of the capacity and inductances, the nodes and lopes of the stationary wave may be varied so as to produce maximum current or maximum potential at the detector, depending on the form used.

Detectors.

Each portion of a receiving circuit in a space through which electromagnetic waves are passing is subjected to an alternating electric force followed by a magnetic force at right angles to it, and all wave detectors are devices for detecting the existence of these forces.

The most general forms of detectors may be classified under the following heads: **Contact, thermal, magnetic,** and **electrolytic** detectors.

Contact Detectors.—The most usual form of contact detector is known as a **coherer,** and there are many patented varieties of this device. In its elementary form, it consists of an exhausted glass tube, provided with little pistons, which act as terminals for connection to the receiving circuit, and between which is some form of powdered metal. The conduction of powdered metal acts in a peculiar manner. A loose heap scarcely conducts electric currents at all, owing generally to the want of adhesion of the particles and to the resistance of air films between the particles. If an electric oscillation occurs near such a coherer, the powder becomes a good conductor and the particles cohere, as the resisting films of air are broken down by the successive internal discharges from one particle of the powder to another, and it will remain a good conductor until the continuity of the particles is destroyed by shaking or striking them.

The electromagnetic waves striking the circuit of which the coherer forms a part, induces an oscillating current through the coherer powder which causes a succession of very minute sparks from one particle to another and which produces electrical con-

tinuity throughout the powder. The coherer is inserted in a local circuit with a few cells in series with a relay, and when current flows from the local battery through the coherer and relay, the attraction of the relay armature closes another circuit which contains the recording instrument.

The coherer is used in the Slaby Arco system and is illustrated in Fig. 394.

Detectors of the coherer type are now rarely used in ship installation, having given way to other forms and principally to some form of electrolytic detector.

Carborundum Detector.—This wave responsive or wave detecting device comprises a body of crystalline silicid of carbon, known generally as carborundum. The body of crystals forming the mass is composed of carbon and silicon in a chemical combination, forming what is known chemically as carbid of silicon, or silicid, or more

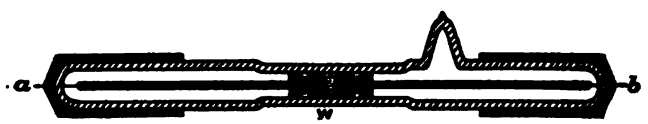


FIG. 394.—Slaby Arco Coherer.

generally as carborundum. It is a highly refractory material, extremely hard and is relatively a poor conductor of electricity.

This substance may be connected in the receiving circuit in many different ways, all of which act efficiently as wave detectors. It should be interposed between the connecting wire from the aerial and the connecting wire to ground. It may be simply interposed with the two connecting wires secured to it in any suitable way, either by direct contact, or through contact pieces holding the carborundum; or it may be held between the points of adjusting screws which are connected respectively to the aerial and ground. Again the carborundum may consist of two pieces, each in connection with the connecting wires and resting lightly against each other on relatively sharp edges.

One of the connecting wires may be connected to a piece of carborundum, a sharp point of which may rest in an electrolyte, such as mercury, or an acid, or an alkaline fluid, while the con-

necting wire to the ground is secured to the vessel containing the electrolyte, if it is a conductor; or it may be immersed in the electrolyte or even connected to another piece of carborundum which rests in the fluid.

In all cases, the usual telephone receiver is connected around the detector with a battery included in the circuit; although if the two ends of the detector are connected to the ends of a looped aerial, one side of which is grounded, the battery may be dispensed with, if the telephone receiver is connected to the same points on the aerial.

Crystalline Detectors.—The carborundum detector is one form of many crystalline detectors whose action in cohering or decohering is not thoroughly understood. One other form that seems to depend upon the resistance of imperfect contacts consists of two crystalline minerals, *zincite* and *copper pyrites*. If a piece of copper pyrites is secured to the connecting wire from the aerial and a piece of zincite to the ground connection, there can be found one degree of contact between them which acts as a very perfect detector; the usual telephone receiver and battery being connected around the contact of the two crystals.

Thermal Detectors.—One form of detector based on thermal action is used in the Fessenden system, although the system as applied to ships of the navy uses a form of electrolytic detector.

The principle of this thermal detector depends upon the property of metals presenting a higher electrical resistance as their temperature increases. It consists of a silver wire bent into the shape of a V having a diameter of .05 mm. with a core of platinum .0015 mm. in diameter. The lower end of this V is immersed in nitric acid, which dissolves the silver for a short length of the platinum. The wire is contained in an outer covering of silver, which is held in a glass vessel from which the air has been exhausted, and through which connecting wires lead from the outside and are soldered to the silver wire.

When the exposed platinum wire at the point of the V is in circuit with the electric waves, it heats rapidly, and as rapidly cools when the wave ceases. In the same circuit is placed a battery and a telephone, the variation of the resistance producing variations in the telephone current which produces sounds more or less pro-

longed, according to the train waves, and these are longer or shorter as the wave trains sent out by the sending circuit or of greater or shorter duration.

Magnetic Detectors.—This form of detector is based on the principle that rapidly alternating currents permanently modify the magnetization of a magnetized steel bar. The electric waves striking such a magnetized bar induces currents in a conductor wound around it which may be made manifest in several ways. After a change in the magnetization due to the impact of the oscillating current, it must be remagnetized before it is in a position to again be affected. The general principle is exhibited in Fig. 395.

The magnetized substance is a bundle of very fine steel wires, insulated one from another. Around this is wound the aerial, with the other end connected to earth. Over this is a coil of a

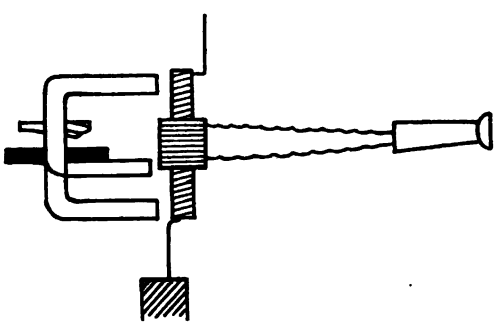


FIG. 395.—Magnetic Detector.

great many turns of fine wire to which a telephone receiver is connected. Due to the demagnetization of the bundle of wires currents are induced in the coil which traverse the telephone and owing to their alternating character produce sounds, of a duration depending on the length of wave train.

The magnetism is restored by a revolving horseshoe magnet which constantly remagnetizes the bundle of wires.

This form of detector was devised by Marconi but has not been used in ships of the Navy. Its practical working form is different but the principle remains the same.

Electrolytic Detectors.—This form of detector depends upon the power of electric oscillations to affect the polarization of small metallic surfaces immersed in an electrolyte. The general principle in most detectors of this type is explained in a description of the Schlœmilch Detector. This is illustrated in Fig. 396.

A primary cell is arranged to consist of two electrodes, one of platinum, *A*, and the other lead, *B*, and the electrolyte of dilute acid. The platinum anode *A* is made very fine, both in its length and diameter, being about .01 mm. long and .001 mm. in diameter, and arranged so that the point just touches the surface of the electrolyte.

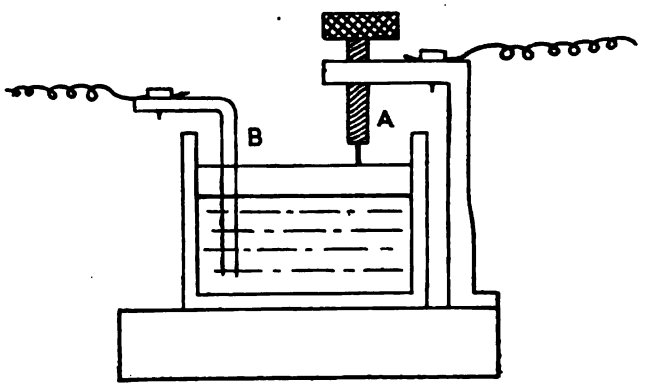


FIG. 396.—Schlœmilch Detector.

This electrolytic cell is placed in series with another primary battery with a slightly higher E. M. F. and included in the same circuit is a resistance coil and telephone receiver. This primary battery sends a small current through the electrolytic cell and soon *polarizes* the electrodes; that is oxygen gas is liberated from the acid by the current and the bubbles collect on the small platinum anode. The resistance of the gas so increases the total resistance that the current from the primary battery soon falls to zero, or practically so.

If now the electrolytic cell is connected to a circuit in which electric oscillations are set up, these oscillations momentarily depolarize the surface of the platinum anode, which suddenly reduces

the resistance of the cell. Current then as suddenly flows from the primary battery, and through the telephone in which a sound is heard, its duration depending upon the impact of long or short trains of waves. These sounds are then of shorter or longer duration, corresponding to the dots and dashes of the telegraphic code, the length of train wave made by the length of time the sending key is kept in contact.

The electrolytic cell as practically used varies in details, some using platinum cells as in the Fessenden type, others glass cells as in the De Forest type. It is usual to seal the fine wire of the anode in a glass tube, leaving just the minutest portion of the surface exposed. In this form the tube may be immersed in the electrolyte, and the care necessary to keep the fine point adjusted to the surface of the liquid is eliminated.

In order that the potential of the primary battery may be adjusted to the proper value for just polarizing the anode in the electrolytic cell, its terminals are connected through a potentiometer or variable resistance whereby the current can be accurately controlled. All forms of wireless sets used on ships of the Navy are so connected with the exception of the Shoemaker type.

The Shoemaker type of electrolytic cell does not require an extra primary battery, but uses its own current to depolarize itself. It consists of a fine platinum wire sealed in glass as the positive electrode and amalgamated zinc as the negative electrode, both dipping into an electrolyte of 20 per cent solution of sulphuric acid. The telephone receiver is simply shunted across the terminals of the detector.

Detector Circuits.

Referring to Fig. 393, in which elementary diagrams of various forms of receiving circuits are shown, the detector in each case is marked *D*. The detector circuits shown in Fig. 397 may be considered the complete diagram of the detector circuits.

Inductance and Capacity of Receiving Circuits.

The object of inductance and capacity in the receiving circuit is to give it a certain period of vibration in order that it may respond

to a certain frequency or wave length of the sending circuit. As the natural frequency depends upon both of these factors, and for the purposes of changing the wave length, it is usual to fit the receiving circuits with both variable inductances and capacities.

Variable Inductances.—Variable inductances are usually of the step-by-step or roller form. A convenient form of step-by-step inductance is made by making a cylindrical coil of insulated wire

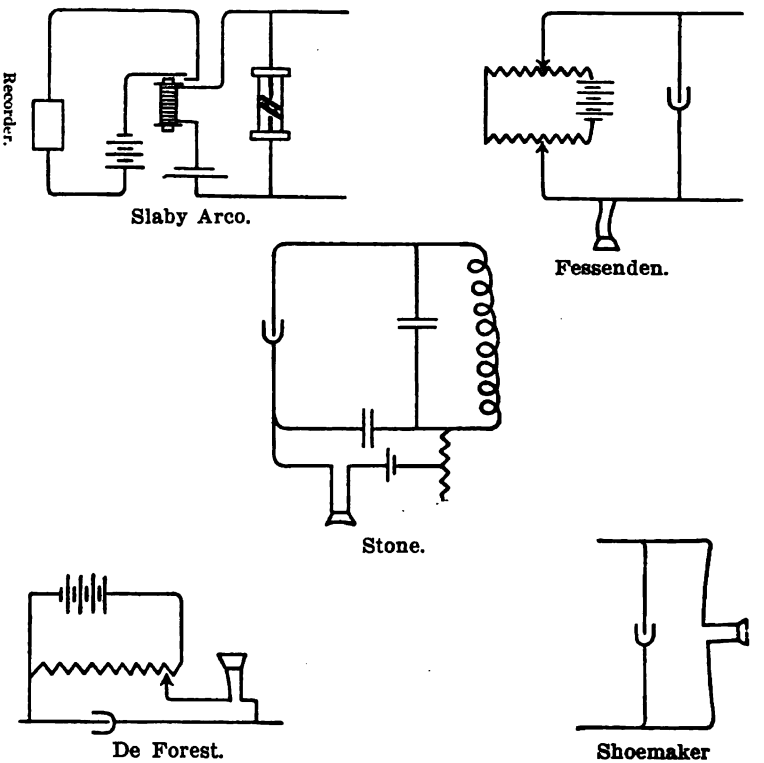


FIG. 397.—Detector Circuits.

wound on glass, or some form of hard rubber with one point on each turn bare. A sliding contact moves across these points, giving as many adjustments as there are turns in the coil.

Step-by-step inductances are also sometimes made with plug steps, giving a limited number of changes.

Roller type of inductances may be of the single-roller or double-roller type. In the single-roller type a bare wire is wound on a groove cut in an insulating cylinder, and against this wire is pressed a sliding contact. By revolving the cylinder any fraction of its length can be put in circuit. In the double-roller type a bare conductor runs from one insulating cylinder to another. On one cylinder the turns of the wire are insulated and on the other they are in contact, so any desired length can be added to the circuit.

Variable Capacities.—These are generally of the step-by-step or sliding type previously described.

Variable capacities in receiving circuits are more essential than variable inductances, as a strong pronounced natural period can only be obtained by a large inductance, leaving the variation in wave length to be accomplished by the variable capacities. If the wave length is to be very greatly increased it can be done by adding a large inductance to the aerial at some point that will not interfere with the inductance necessary for the absorption of power in the closed circuit.

PART V.

WAVE METERS.

In any circuit containing resistance, capacity, and inductance, if the resistance is small in comparison with the inductance, the number of oscillatory vibrations per second such a circuit will follow will be given by the formula:

$$n = \frac{1}{2\pi\sqrt{KL}},$$

where K = capacity in farads,

L = inductance in henries,

and n = number of oscillations per second.

Therefore, knowing K and L for any circuit, which values can be found by independent measurement, n may be calculated, from which the wave length may be found from the formula:

$$V = n\lambda \quad \text{or} \quad \lambda = \frac{V}{n},$$

where λ = the wave length, in the same units as V, which is the velocity of the electromagnetic waves or the velocity of light.

Thus the length of wave corresponding to the natural vibration period of any circuit containing inductance and capacity may be found. Wave meters are circuits containing these factors, with provision for varying their values and for each combination of which the wave length has been calculated.

Donitz's Wave Meter.—An inspection of this device (Fig. 398) will show a closed circuit containing inductance and capacity in series. The inductance is in the form of a ring with plug terminals by which it is connected to the condenser. This last occupies the main space devoted to this meter and consists of several semicircular metallic sheets, parallel to one another and fixed; while an equal number of similar semicircular sheets are movable around a vertical axis, and so arranged that they can be fixed to slide more or less into the spaces between the fixed sheets, thus constituting a condenser of variable quantity. These plates are contained within a circular vessel which is filled with oil.

The knob that moves the plates is provided with a pointer which moves over a scale indicating the wave length for the given inductance and the capacity of the condenser corresponding to the position of the plates at that time. The instrument is provided with three separate inductance coils of values 2.8, 12.1, and 50 microhenries, and there are three scales provided, one to be used for each of these coils.

The indicating apparatus shown on the left consists of a very small spiral of platinum sealed in an air thermometer, and connected inductively to the main circuit.

When the circuit is vibrating in its natural frequency, the greatest current is induced in the platinum spiral which is heated and the air thermometer then registers its maximum value.

Slaby's Helix Wave Meter.—This form of wave meter depends upon the principle that if a helix of uninsulated wire is held in the hand and the other end held near a circuit in which electric oscillations are taking place, the length of the helix can be altered until the stationary oscillations excited in it are of the same frequency as those in the circuit under test. The wave length will then be four times the length of the helix.

The practical instrument is made of an insulated copper wire

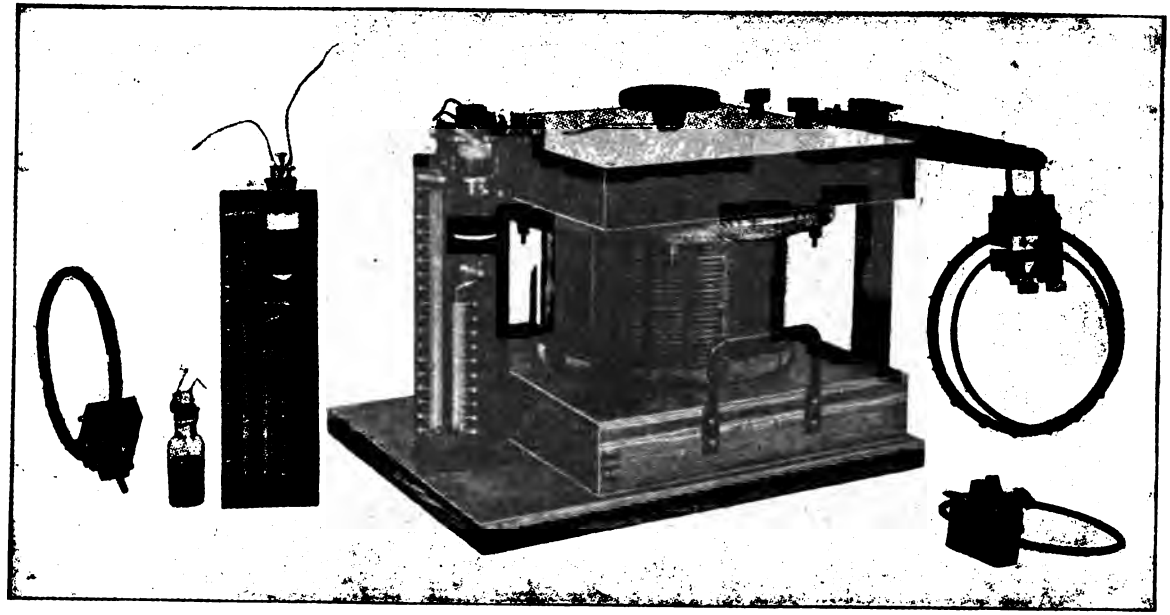


Fig. 398.—Donitz's Wave Meter.

wound in a close spiral on a glass tube ¾ inch in diameter. The lower end of the copper wire is in connection with a metal handle attached to the glass tube while the upper end is in connection with a fluorescent sheet. This is formed of a small sheet of paper covered with crystals of barium platino cyanide with gold-leaf in a fine state of division rubbed on the surface. This prepared paper is then inserted in the upper end of the tube and held by a stopper.

A metal rod is provided which is connected to an earthed wire. When the end of the tube containing the fluorescent paper is held near the circuit in which the oscillations are taking place and the earthed rod is moved along the spiral, there will be a point in which the glow in the prepared paper is greatest. At that point the wave length is read on the scale opposite the metal rod.

Fleming's Wave Meter.—This form of wave meter also depends upon the establishment of **stationary waves** upon a helix brought near an oscillating circuit. Its general construction is illustrated in Fig. 399.

The inductance consists of an ebonite tube with a helical groove cut on it, in which is wound bare copper wire whose ends are secured to collars on the ebonite tube. Parallel to this helix is fixed a sliding tubular condenser. This consists of inner and outer tubes of brass with a tube of ebonite between them. The outer tube has a collar k at one end to which is attached an ebonite handle h. A movement of this handle moves also a collar K on the inductance and carries a pointer which moves over a scale SS. One end of the inductance helix is connected to the inner tube of the condenser through the bar $L_1L_2L_3$. A vacuum tube V, preferably one filled with rarefied neon is connected with one end of the inner condenser tube and the other end should be connected to earth, when measuring wave lengths.

To measure the wave sent out by an aerial, the handle h is moved until the vacuum tube glows most brightly and the scale reading will be the wave length.

The form of wave cannot be plotted by this meter as there are no means of determining the relative brightness of the glow, but it will only show the length of the two waves radiated by the aerial.

In addition to being used as a wave meter, this instrument can

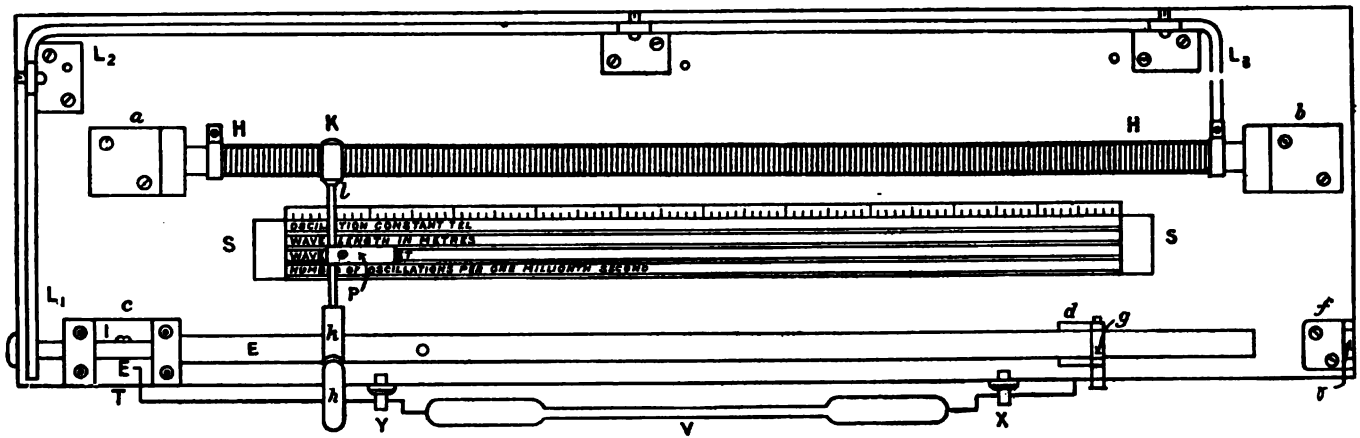


FIG. 399.—Fleming Wave Meter or Cymometer.

also be used to measure small inductances and capacities, one reading of the scale showing the oscillation constant, $\sqrt{KL}$, expressed in centimetres.

Hot Wire Ammeter.—This instrument is for use in the open circuit and measures directly the current in the aerial, and to be accurate the whole current should pass through the working wire of the instrument. As its name implies it measures the heat generated in the aerial, and the heat generated acts to expand a conductor which moves a pointer over a scale indicating the number of amperes flowing. If the pointer moves off the scale, its terminals are shunted by suitable resistances whose values are known.

When the closed and open circuits have the same frequency a maximum reading will be obtained on the ammeter, but it will not in any way indicate the wave length or degree of coupling of the two circuits, though it will show the difference of energy radiated dependent upon the tightness or looseness of the coupling.

Pierce Wave Meter.—The Pierce Wave Meter is very similar in design to the Donitz Meter. The place of the air thermometer is taken by a telephone receiver and it is fitted for measuring both long and short waves, and when used with the former, there is included in the circuit an extra inductance coil of fine wire. When the frequency of the meter and oscillating circuit are in tune, the humming noise produced in the telephone receiver is a maximum, and a slight change from complete resonance will destroy the sound.

The wave meter can be used as a sender by disconnecting the telephone receiver and substituting in its place a small spark gap, which can be actuated by a small spark coil.

PART VI.

TUNING.

By tuning or syntonizing is meant the operation of connecting the different circuits of a wireless outfit so that they shall all vibrate in the same period, or adjusting the closed and open circuits of the sending and receiving circuits to the same wave length.

There are two conditions necessary to insure the tuning of two

stations with one another; the sending apparatus should radiate waves of well-defined period and but slightly damped, if at all, and the frequency of vibration of the different circuits should be capable of easy adjustment.

Between two stations tuned for the same wave length it is possible to signal with sending apparatus of much less power and to receive with apparatus of less sensibility than if they were not so tuned.

The different circuits are tuned by means of any of the standard wave meters previously described, the operation consisting in setting the pointer opposite the desired wave length and then bringing the circuit under test in syntony with it by changing its variable factors. Most sending circuits have fixed capacity and variable inductance, while in receiving circuits, the opposite is the case. If variable inductance is needed in a receiving circuit, it can be placed where it will not affect the mutual induction of the closed and open circuits.

The question of wave length is one dependent on the possible length of aerial with due consideration of sufficient inductance for proper coupling. The greater the wave length the more power can be used, and it has been shown that long wave length is of advantage in passing around obstacles when sending over land. Four hundred and twenty-five meters has been adopted as the standard wave length for ships of the Navy.

The sending circuits are usually tuned first and the closed and open circuits are tuned separately.

To Tune the Closed Sending Circuit.

By Donitz's Wave Meter.—Disconnect the closed circuit from the open circuit, if it is directly connected. Set the pointer that moves the variable capacity of the meter to the desired wave length, and connect one of the inductance coils to its terminals. Bring the inductance coil of the meter parallel to the plane of the inductance of the closed circuit and close to it, a foot or so, and arrange so that the circuit produces a clear, bright spark of moderate length. This will induce oscillating currents in the meter circuit and produce heat in the thermometer coil and the thermometer will indi-

cate a certain reading. Now vary the inductance of the closed circuit until the thermometer gives its maximum reading. The two circuits will then be vibrating in tune, and the wave length of the closed circuit will be the same as that of the meter. Note the number of turns of inductance in circuit.

By Slaby's Wave Meter.—Hold the end of the spiral at which the fluorescent paper is placed to the circuit in which oscillations are taking place and move the earthed rod along the spiral until it is opposite the desired wave length. Then vary the inductance in the closed circuit until the brightest glow in the fluorescent paper is produced. At that time the closed circuit has the wave length indicated by the rod.

By Fleming's Wave Meter.—Move the handle that changes both the inductance and capacity until the pointer is opposite the desired wave length. Bring the copper bar which joins one end of the inductance spiral to the inner tube of the condenser parallel to the plane of the inductance coil of the closed circuit. With a clear, bright spark as before, start the oscillations of the closed circuit which act inductively on the circuit of the meter. Vary the inductance of the closed circuit until the vacuum tube glows most brightly, at which time the circuit has wave length indicated by the pointer.

By Pierce's Wave Meter.—Set the pointer moved by the handle of the variable capacity to the desired wave length. Produce the spark in the closed circuit as before and bring the inductance coil of the meter near the inductance of the circuit under test. Place the telephone receiver to the ear and vary the inductance of the closed circuit until the maximum sound is produced in the telephone. When this is the case the two circuits are in tune.

To Tune the Open Sending Circuit.

Disconnect the closed and open circuits in direct-connected sets as before, and arrange a small spark gap in the aerial in series with it and the ground, and to the terminals of this spark gap add a small spark coil, or connect them to the terminals of the induction coil and have just enough energy to give a clear, bright spark.

If the aerial is inductively connected, remove the inductance to first find the natural period of the aerial.

By Donitz's Wave Meter.—Bring its inductance coil parallel to the aerial. For this purpose a special coil of one turn is furnished for insertion inside the wave meter inductance, and connect this in series with the aerial. As the capacity of aerials is comparatively small, this is done to bring the inductance coil of the meter very close to the aerial. Now vary the capacity of the meter until the maximum reading is obtained, when the natural frequency of the aerial will be indicated by the pointer.

At the same time, it is well to insert the hot wire ammeter in the aerial and note and record its reading for the natural period of vibration.

By Slaby's Meter.—With everything as before, approach the fluorescent end of the helix and move the rod along it until the maximum glow appears. The reading then opposite the movable rod is the wave length due to the natural period of the aerial.

By Fleming's Meter.—With the previous arrangement bring the upper bar parallel to the lower part of the aerial and about 3 or 4 inches from it. The terminal of the vacuum tube which is connected to the outside of the sliding condenser should be connected to earth. Move the handle along the inductance coil until the maximum glow appears in the vacuum tube when the reading opposite the pointer will be the natural period of the aerial.

By Pierce's Wave Meter.—Approach the inductance coil of the meter to the oscillating aerial and close to it, and with the telephone receiver to the ear, move the handle of the condenser. When the maximum sound is heard, the pointer indicates the natural period of the aerial.

After the natural period of the aerial has been obtained by any of the above means, the wave length can be brought to tune with the closed circuit by setting the indicators to the proper wave length in the different forms of meters, and adding a sufficient number of turns of the common inductance in direct-connected sets or of the aerial inductance in inductively-connected sets to give the same frequency as the wave meters, being indicated by the maximum readings of the meters, according to their construction.

Wave Forms.

By the use of Donitz's Wave Meter it is possible not only to obtain the maximum reading of the thermometer, at which time the wave length is indicated, but other readings may be obtained with other positions of the index of the variable capacity, and in this way a series of points may be obtained through which curves may be drawn giving the wave form.

For these curves, wave lengths or indications of the capacity index, are used as abscissæ and thermometer or hot wire ammeter readings, as ordinates according to some convenient scale, and curves are drawn through the points so plotted. They can be plotted for the natural length of aerial; for the aerial with its inductance; and for the natural closed circuit.

A study of these curves will in a general way indicate the sharpness of their resonance and the distribution of energy.

Coupled Circuits.

After the closed and open circuits have each been tuned separately, they are then coupled together. If the wave length is tested after the circuits are coupled, it will be found in general that there are two points of maximum intensity indicated by the wave meters, indicating two wave lengths, though as a matter of fact, the wave curve shows one wave with two humps. If the curve is plotted with wave lengths as abscissæ, and either thermometer or hot-wire ammeter readings as ordinates, one hump will be found to have a greater and the other a less value than the wave length to which one of them separately was tuned.

The **percentage of coupling** is the ratio of the difference between the two maxima to the natural wave length of each circuit, and if closed coupling is desired, the mutual induction between the two circuits is then varied until the two maxima are at the desired points. If very loose coupling is desired, the mutual induction is varied until but one maximum is indicated by the wave meter and this will be very near the natural wave length of each circuit when not coupled.

To Tune the Receiving Circuit.

Receiving circuits should have strong natural periods of vibration, and this can be obtained by large inductances, leaving the tuning to be accomplished by variable capacities. Adding large inductances to the aerial for receiving to increase the natural period, does not have the bad effect of adding it for sending, as it will receive waves of almost any length, but will radiate only feebly if its period is far removed from its natural period. If the receiving circuit has high resistance, the open circuit should be adjusted to the wave length of the sender. However, adding inductance to the closed receiving circuit beyond a certain value, is of no value, as no increase of the natural period will serve to strengthen the signals.

As close coupled senders radiate two waves, one longer and one shorter than the natural period of each, it is possible to adjust the receiving circuit in tune with either wave, but experiment shows that best results are obtained when both the open and closed receiving circuits have the same natural period as the sending circuits and have the same coupling. The longer wave has the lower frequency and has the least damping and consequently greater amplitude or intensity, and if the receiving circuit is to be tuned with only one wave, it would be more advantageous to syntonize with the longer one and disregard the other.

Tuning by Wave Meters.—Of the various forms of wave meters described, only two, the Donitz and Pierce can be used for tuning receiving circuits.

The Pierce Wave Meter is supplied with a special spark gap. The telephonic receiver is removed and the spark gap supplied is put in its place. This attachment has a coil in its base of the proper inductance to replace the telephone. The spark gap should be actuated by a small spark coil by attaching the secondary of the spark coil to the two sides of the wave-meter spark gap which should be opened not more than .1 to .2 of an inch.

The index on the capacity is then set to the proper wave length and the meter used as a sender. It should be placed about three meters from the aerial. Conditions of resonance of the meter with the receiving circuit will be indicated by the maximum sound in

the receiver telephone and can be effected by changing the inductance in the receiver tuning coil.

The Donitz Wave Meter may be used in the same manner as a sender, by arranging a spark gap in the circuit and actuating it by a small spark coil.

It is usual to calibrate one of the elements of receiving circuits. They have either fixed inductance with variable capacity, or vice versa. For one given value of one element, the other may be marked in wave lengths according to its varying values. Thus, in the Stone set, which consists of three coils, inductively connected, the second is calibrated. All have fixed inductances and variable capacities. With the fixed inductance, the frequency or wave length is calculated from different capacities, and the resulting wave length is marked on the handle which moves the condenser plates.

In such cases, if the values of the variable elements are known for different positions of the controlling devices, the tuning can be effected without wave meters, as the different circuits will be in tune with each other when the product of the inductance and capacity in each is the same.

CHAPTER XXXVII.

PRINCIPLES OF WIRELESS TELEPHONY.

Wireless telephony differs from wireless telegraphy in that it transmits articulate sounds while telegraphy limits itself to the transmission of inarticulate sounds, which are made the basis of a code by which words may be sent or received in the form of messages. In telegraphy the sound produced in the telephonic receiver is that due to a certain number of vibrations which fall within the range necessary for the production of sound and the frequency or period of the vibrations is not important; but for the reproduction of articulate sounds, there must be a very wide range of frequencies to correspond to the immense number of vibrations of which speech is composed.

The range of frequencies for the production of sound vary between 16 double vibrations per second and 40,000 double vibrations, the former giving the lowest audible sound and the latter the highest musical note. For the average man's voice, the number of double vibrations per second is 128, and for the average woman's voice, the number is from 256 to 512.

The efforts of the earlier experimenters in wireless telephony were directed to the idea of using the connection afforded by the earth. In general, the scheme consisted in stretching two parallel wires, one at each station, the extremities being taken to earth. In one of these wires was inserted a microphone with a battery of dry cells, and in the other a telephone which reproduced words pronounced at the microphone.

Although such schemes did not require a connecting wire between stations, yet the total length of the parallel wires at the two stations was required to be about the same length as the distance between the stations. Such a telephonic circuit has been in operation for some years in England, where communication is held between the lighthouse on the Isle of Skerry and the coast-guard station of Cemlin, a distance of about three miles.

Theoretical Principles.

In 1878, two American physicists, Graham Bell and Sumner-Tainter discovered that a beam of light that had been made intermittent, falling upon a thin sheet held against the ear, gave a sound, the number of whose vibrations is equal to the number of interruptions in the source of light. By making the duration of the intermissions longer or shorter, the duration of the sound produced was longer or shorter. Any source of light whose intensity can be varied can be used in this experiment but the distance to which the phenomena can be manifested is increased by using a receiving circuit composed of a selenium resistance in series with a telephone and battery.

Crystalline selenium has the remarkable property of being a much better conductor of electric currents when illuminated by a beam of light, and of increasing its conductivity with the intensity of the light. If such a resistance is exposed to a luminous radiation of variable intensity, the variations of intensity will cause variations in the resistance of the selenium and consequently in the battery circuit which will vary the current flowing through the telephone and which will in turn emit sounds corresponding to the changes in the quantity of light.

If the electric arc is used as the source of light, variations in intensity may be produced by certain properties it possesses when arranged as discovered by Duddel, and known as Duddel's singing arc.

Duddel's Singing Arc.—If an alternating current of small intensity be placed in a favorable condition in respect to a continuous current which is feeding an electric arc, the arc itself will emit a sound. At the same time equal oscillations are produced in the light of the arc. If the alternating current is set up in the circuit of a microphone by speaking in it, the oscillations produced in the arc can be received by a selenium receiver placed at a distance, and the luminous oscillations will cause the spoken words to be reproduced in the telephone in the receiving circuit.

The alternating current may act on the circuit which feeds the lamp in a shunt circuit from the feeding circuit, or it may be in another circuit which acts inductively on the feeding circuit.

Fig. 400 shows the connections for the first condition.

R is a resistance wound on a soft-iron core, around which passes the whole of the current feeding the arc. From the ends of the coil is connected a microphone *M*. *R* can be so adjusted that a battery in connection with *M* will be unnecessary. As the microphone is spoken into, the variations in resistance caused by the sound waves changes the current feeding the arc and the light of the arc will vibrate in rhythm with the diaphragm of the microphone and similar vibrations will be set up in the selenium receiver and the words will be reproduced in the telephone of the receiving circuit.

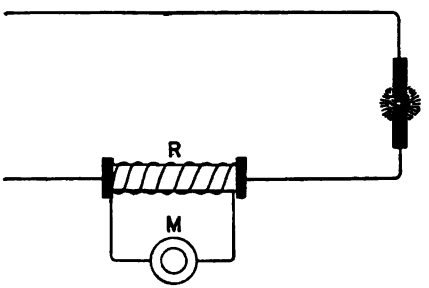


FIG. 400.—Duddel's Singing Arc.

Explanation of the Singing Arc.—In the phenomenon of the singing arc, the variation of the feeding current caused by the superposition of the current due to the microphone develops greater heat in the arc, as the heat is proportional to the square of the current. Similar variations in the volume of the incandescent gases forming the arc are caused by this variation in heat, and these variations in volume are those which generate sound vibrations in the air, reproducing the vibrations in the microphone, and causing the arc itself to sing.

Duddel's Circuit.—In this circuit, the extremities of the arc are joined with a circuit comprising a capacity and inductance as shown in Fig. 401.

D is a generator supplying continuous current to the arc *L*, joined to the extremities of which is a circuit composed of a capacity *C* and inductance *I''*. Such a circuit has a natural period of electrical vibration depending on the values of the capacity and inductance.

If certain conditions are satisfied at the instant when the circuit of the arc is made, the condenser becomes charged and discharged with a frequency depending on the oscillation period of the circuit, thereby producing alternating currents which overlap the continuous current feeding the arc and cause it to vibrate with a period equal to that of the alternating current and the rest of the circuit. If this frequency lies within the range of percepticle sounds, the arc admits a musical note.

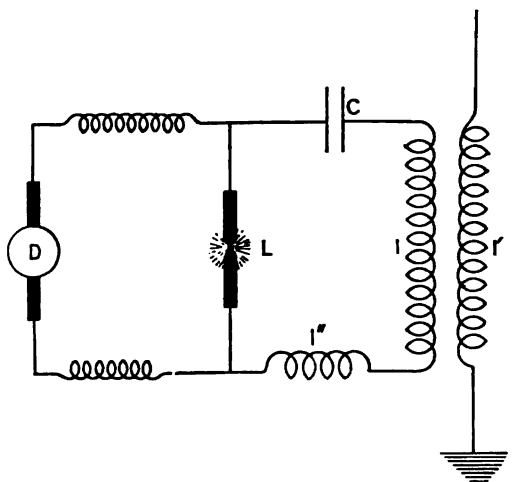


FIG. 401.—Duddel's Circuit.

If the arc is made between the poles of a powerful magnet, either permanent or an electromagnet, both the frequencies and intensities of the alternations are much increased.

This oscillating circuit does not radiate its energy, and to produce radiation, the circuit may be inductively connected through an air transformer to an open circuit which may be made an aerial similar to that of wireless telegraphy, one end being grounded. This transformer is shown at I, I', where I is the primary of the transformer inductively connected to the secondary I' which forms part of the aerial, the lower end of which is grounded.

The portion of the circuit $LCII''$ is known as **Duddel's circuit**. This circuit has very little damping, and almost perfect resonance

may be obtained in two circuits, which is very powerful in case of coincidence of frequency of vibration, but which falls off rapidly when the resonance is less perfect.

In such an arrangement as shown in Fig. 401 under certain conditions there would be a continuous radiation from the aerial of a definite period and amplitude. If the amplitude of these waves could be varied by the vibrations due to the voice, the train of radiated waves would consist of all the elements necessary to the transmission of speech.

Such a condition is effected by introducing a microphone in the aerial between the secondary and the ground. If this is now spoken into, the constant radiated energy of the aerial will have superimposed on it the varying energy caused by the changes in the microphone resistance and consequently the radiated waves will have all the varying amplitudes caused by the sounds of the voice speaking against the diaphragm of the microphone.

Electromagnetic Waves.

From the preceding explanation it will be seen that the waves radiated from the aerial of a wireless-telephone sender differ from those of a wireless-telegraph sender in that the amplitude of each wave in a wave train from the former varies according to the impulses that have been given to it by the voice and consist of all the various irregularities of amplitude that are characteristic of sound waves, while those from the latter are probably of nearly equal amplitudes. Aside from this difference the two series of waves are practically the same, with the same characteristic vibrations of the ether at right angles to each other, and are propagated through space in the same manner, guided by the earth through which the lines of force are completed.

Receivers.

The receiver necessary to reproduce every fluctuation of the energy of the transmitter may be any of the various forms of automatically restoring responders using a telephone receiver, such as the imperfect contact coherer, magnetic detector, electrolytic detector, the carborundum or silicon detector. The one said to be the

most sensitive and to give the clearest quality to the reproduced tones is the "Audion," or hot-gas responder, devised and patented by Doctor De Forest, and which can also be used in wireless telegraphy.

Audion.—The Audion consists of a device for detecting feeble electrical currents or oscillations, particularly such as are developed in wireless telegraph or telephone systems. The Audion itself comprises a receptacle, which may be partly exhausted, including a sensitive, gaseous conducting medium, and in which are two electrodes of suitable conductors.

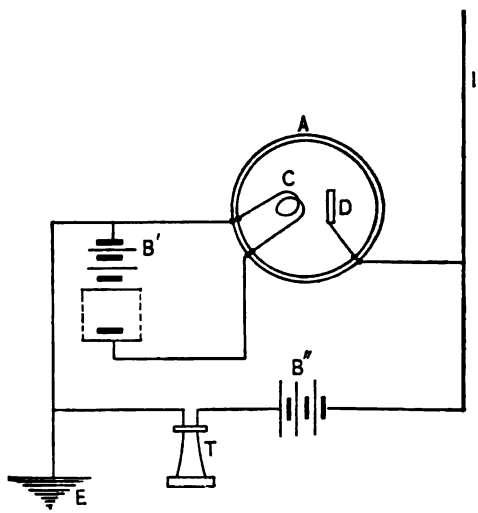


FIG. 402.—Connections of Audion.

The elementary connections of the Audion to the wave intercepter and the signal-producing device are shown in Fig. 402.

In the figure *I* represents the wave intercepter, or the aerial of the telegraph or telephone installation, connected with the earth at *E*. *A* is the Audion with its two electrodes *C* and *D* inclosed within it and which contains air partly exhausted, or a gas containing compounds of the halogens or halogen salts, or mercury vapor. *C* is an ordinary incandescent lamp filament and is connected to a bat-

tery B'. The electrode D may be any suitable conductor, as a plate or disc of platinum.

The gaseous medium inclosed between C and D is rendered sensitive to electrical oscillations by the radiation of heat from the electrode C which is heated by the battery B'.

The passage of electrical oscillations across the gap between the electrodes alters the conductivity of the gas in the gap, and connected in series with this gap is a circuit containing a telephone T and battery B''. When the electric oscillations pass across the gap, the change in the conductivity of the gas produces current variation in the circuit containing the battery B'', causing the telephone, T, to respond. The telephone may be connected either in series or in shunt with the electrodes. The aerial may be connected to either electrode, in which case the other must be connected to earth.

The voltage to be impressed on the electrodes C and D by the battery B'' depends on the nature of the gas between the electrodes and upon the degree of exhaustion within the receptacle, a voltage from twenty-five to one hundred and ten volts is sufficient, the needed voltage decreasing with the degree of exhaustion.

This device is free from all the adjustments required of those detectors that depend for their operation upon variation of resistance of an imperfect electrical contact or counter E. M. F. of a polarization cell.

De Forest Wireless Telephone.

This system designed by Dr. De Forest and made by the Radio Telephone Company of New York has been installed on many of our ships of war. The system is based upon the modulation by a telephone transmitter of trains of electromagnetic waves of relatively high frequencies. These waves are generated in a way, following the methods shown by Thomson and Duddel, such that the frequency of the oscillations becomes so great as to enter the range of Hertzian waves, at which frequencies, energy begins to be radiated into space from the aerial wires.

The direct-current arc is used in connection with an alcohol flame, special arrangements being made to render the arc quiet and free from hissing or popping sounds which would render the

reception of speed more or less obscure. To adapt an arrangement of the low-potential arc to wireless transmission of speech it is necessary to secure a spark frequency exceeding the tones used in speech, and if this frequency be higher than that, having for example, over 40,000 vibrations per second, the pitch of the aerial vibrations produced by the spark becomes so high as to make them inaudible to the human ear, and the articulation and clearness become perfect.

The 40,000 double vibrations correspond to a wave length of

$$\frac{300,000,000}{40,000} = 7500 \text{ metres.}$$

The variation of the amplitude of the radiated waves is accomplished by placing a microphone transmitter in the earth lead of the aerial between an inductance and the ground; this inductance being inductively coupled with the closed oscillating circuit. The microphone is placed near the ground where the high-frequency currents are maximum and the potentials are the least.

The general elementary diagrams of this system is shown in Fig. 403, and the sending circuit can be studied in connection with the Duddel circuit shown in Fig. 401. The receiving circuit can be readily understood from the description of the Audion previously given.

The diagram of connections is shown in Figs. 404 and 405, and with the help of those of Fig. 403 will be readily understood.

In late installations, the appliances are assembled in a compact form in a transporting case which admits of their use in the chart house or emergency cabin or on the bridge.

Instructions for Tuning and Operating De Forest Radio-Telephone Apparatus.

The following directions are furnished by the makers, the Radio Telephone Company, New York. The lettering refers to Fig. 405:

Transmitter, Type C.

Source of Power.—This should be from 200 to 250 volts direct current. From 2 to 5 amperes give best results. If motor generator is used give to it the care any such machine properly demands.

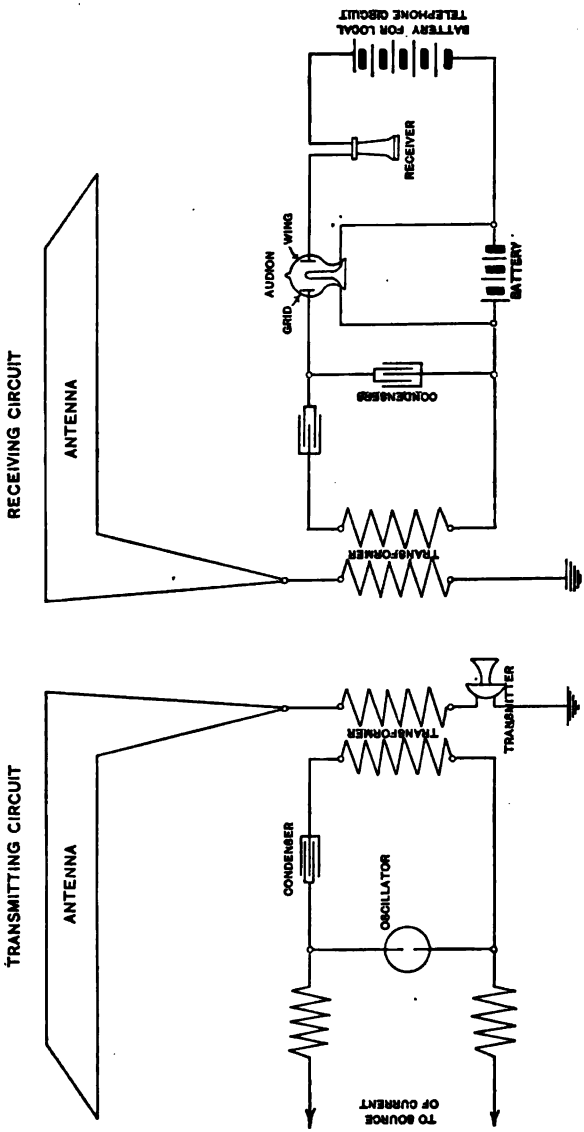


FIG. 403.—Elementary Connections of De Forest Wireless-Telephone Set.

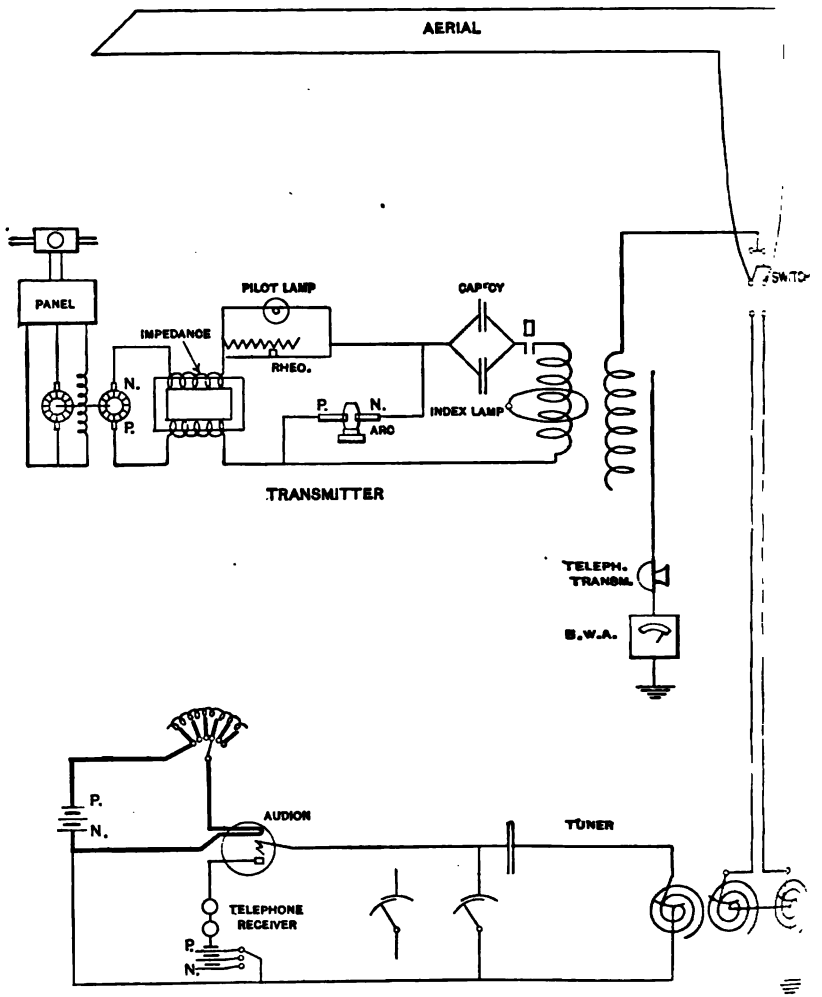
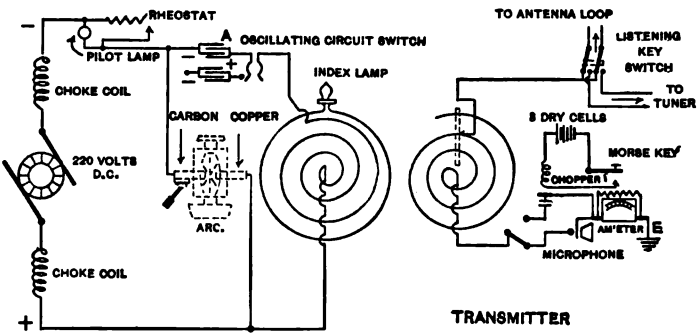
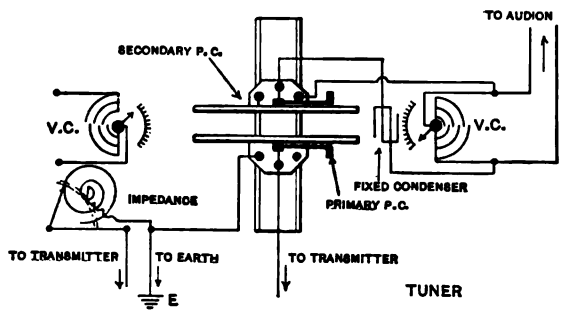


FIG. 404.—Diagram of Connections. De Forest Wireless Telephone Set.





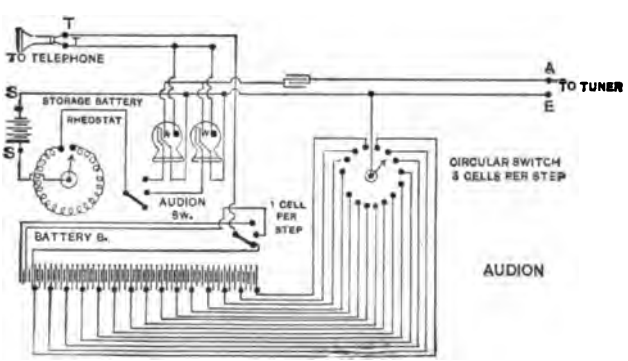


FIG. 405.—Connections of Apparatus. De Forest Wireless Telephone Set.

Rheostat with pilot lamp in shunt thereto must be connected in circuit, preferably between transmitter and choke coil. One choke coil must be in each leg of circuit. Positive lead goes to upper binding post behind lamp (lettered $P+$). This leads to the rear or copper-arc electrode.

Negative lead goes to lower binding post (lettered $P-$). This leads to the lamp bracket and to the front, or carbon, electrode.

Arc Oscillator.—The lamp tank should be kept full of denatured alcohol, and never allowed to get entirely empty. This is important. The tank should be filled full each morning when commencing work.

To facilitate starting oscillator when cold a little alcohol may be poured on wick through top of chimney, but this is not advised.

The opposing faces of the electrodes should be perfectly flat and parallel. After several hours' usage, if arc becomes unsteady withdraw the carbon electrode from the lamp by turning knob counter-clockwise until rack clears the gear. If rough file off the face of the carbon with file supplied for this purpose.

Use no other carbons than those supplied with transmitter.

To Start Oscillator.—Close the main line switch. Turn feed knob on lamp until electrodes make contact and pilot lamp lights, then separate electrodes until pilot lamp glows to half-brilliancy. Resistance of rheostat should be nearly all in so that arc is just nicely self-sustaining; and once properly set need not be touched thereafter.

The arc is out if pilot lamp is not lit.

The arc is closed if pilot lamp is full brilliancy.

Let arc burn until alcohol lamp is well lit, and arc will begin to oscillate.

Listening Key.—This switch must be depressed for transmitting: elevated for listening.

Glow or Index Lamp.—The little 10-volt lamp directly above transmitter arm will glow as soon as arc begins to "oscillate."

Adjust length of arc until this lamp glows brightly—not necessarily at its brightest.

Tuning the Transmitter.

Condenser.—Open transmitter door and cut in sections A, or B, or A and B of condenser, according to length of wave desired.

Section A contains 3 plates.

Section B contains 4 plates; A and B 7 plates.

Both condenser plugs must be on corresponding pegs of the jack, i. e. both on A (right and left sides respectively), or both on B, or both on AB.

Primary Spiral.—The flexible lead and clip can be attached to any bared convolution of this spiral as desired. The outer turn of spiral is recommended as giving longest wave lengths and steadiest operation of the arc.

Secondary Spiral.—With listening key depressed and index lamp burning, now move the slide knob on front of transmitter slowly up and down until hot-wire antenna gives maximum deflection. The secondary, or antenna, circuit is then in tune with primary circuit.

Fine adjustment of tuning is obtained by moving primary spiral towards or from secondary spiral, but loose coupling is recommended.

The arc should not be opened too wide, or ammeter needle will fluctuate rapidly, indicating that arc is unstable and liable to go out.

Talking.—The small switch on transmitter arm is thrown to its upper position for talking. Hold mouth close in front of mouthpiece and talk directly therein. Speak clearly and distinctly, not too rapidly. Talk loudly but do not shout.

Do not thrust the lips into the mouthpiece, as this renders the words muffled and indistinct.

The megaphone will increase the action on the transmitter. Invert it and speak directly into the larger end.

Listening in.—Keep the head phones on the head, and at end of every sentence throw up listening key with fingers or thumb of right hand, to assure yourself that the other party hears you clearly and answers you.

Never attempt to talk unless key is down and glow lamp lit.

With a little practice two speakers will almost unconsciously depress this key when talking and raise same when expecting a reply,

so that two-way conversations can be carried on almost as rapidly as over the wire telephone.

Microphone.—The buttons become warm but not injuriously so.

It is well to occasionally tap upon the case of the microphones with screw-driver to shake up the carbon granules.

If your own transmission is good you should hear this tapping in your own head receiver very clearly. If you cannot hear this (your receiver of course being in proper adjustment) try adjusting the arc, etc., until you do. The larger the ammeter reading (if steady) the better the transmission.

A frying or scratching sound in the adjacent receiver accompanies the properly oscillating arc.

Receiving Apparatus.

Audion Receiver Lighting Voltage.—The Audion filaments are made for 3 volts—2-cell storage battery only. Higher voltages must not be used, otherwise the filament will soon burn out.

Rheostat should be all in when first connecting up a newly-charged storage battery, i. e. have rheostat index arm turned as far in a counter-clockwise direction as possible.

Audion filament should be bright, but not excessively incandescent.

Battery "B."—The telephone battery is inside Audion case. The switch arms for same are on right-hand side of case.

The circular switch cuts in three cells per point.

Lower switch cuts in one cell per point.

Switch arm must not cover two points at one time, as this short circuits the cells.

Adjust voltage until you hear the signals (from some distant station) at their maximum intensity.

If this voltage be made too high the blue cathode arc is seen in the bulb, and sensitiveness is diminished.

Once adjusted both rheostat and "Battery B" switches should remain set. These should not be thrown back to zero when sending. Breaking the Battery A (lighting) circuit also interrupts the telephone circuit, and it is sufficient merely to break this *A* circuit when sending with a powerful spark, in order to prevent the

Audion's responsiveness from being even momentarily interrupted by said spark.

Always cut off storage battery by means of switch on left side of receiver box when Audion is not in use. Do not forget this.

As the storage battery runs down cut rheostat resistance out gradually. Keep a duplicate battery always charged in readiness.

If voltmeter be connected across storage battery see that voltage is never too high for the Audion filament.

Double-Filament Audions.

The double filament has twice the life of a single filament. When first filament has burned out unwrap the small bare copper wire which is coiled around the glass neck of the bulb and tuck it under the little brass clip which is soldered on to the outside cap of the stem; or twist this copper wire around the wire stub soldered to this cap. This will put the second filament in the circuit, and Audion is then to be replaced in its receptacle inside the box.

Connect the red wire lead to small binding post marked red; the green lead to binding post marked green.

Tuning the Receiver.

"Pancake" Tuner.—Have the two tuner pancakes approximately ¼ inch apart at the start. Connect the "Impedance" binding posts one to one lead from the transmitter box and the other to the earth lead. These binding posts are lettered *I* and *E* respectively. Connect the other lead from the transmitter to center binding post of primary p. c. (lettered *A*) and the earth lead to one of the other two binding posts on the p. c. (lettered *O* or *I*). Connect Audion binding posts marked *A* and *E* to the two binding posts on end of tuner box marked *VC*. The lead to *C* leads also over to the binding post (lettered *A*) on the secondary p. c. Connect the flexible lead from the fixed condenser inside the tuner box to the binding post on the secondary p. c. (lettered *O* or *I*).

Adjust the two swinging arms and the "Impedance" arm to give maximum sound in telephone receiver from distant transmitting station.

Then adjust capacity of variable condenser (*VC*) in shunt across the two Audion leads, to further increase signals, or cut this *VC* out entirely, according to length of wave to be received, etc.

Finally, or to cut out interferences, separate the p. c's. by a distance giving the loudest signals, thus "loosening the coupling."

The tuning by means of the contact arms now becomes sharper. For undamped oscillations from the radio-telephone transmitter tuning may be made exceedingly sharp.

A little practice and manipulation will enable one to cut out powerful interferences, and to "bring in" the desired station much more loudly than seems possible on first attunement.

For special work the extra variable condenser (*VC*) at the back of tuner box is to be connected in any part of the tuner circuit where it may be needed; for example, in the antenna lead to primary p. c., or in series in the Audion, or secondary, circuit.

The Audion has an excessively small electrostatic capacity, hence tuning with it is extremely sharp.

By adjustment of Battery B on Audion it is possible under some conditions to effect a separate method of tuning auxiliary to the usual method. But once attuned to a given radio-telephone transmitter this tuner and Audion receiver require little attention.

Antenna.—The "Loop" antenna should always be used in receiving. Connect one end thereof to each of the antenna leads coming out from the top of the transmitter case.

Earth Lead.—This lead should be as short as possible from "Earth" to the hot-wire ammeter and thence to lower binding post (marked *E*) on transmitter case. Run a spur lead from earthed side of ammeter to the "Impedance" binding post lettered *E*, and to binding post marked *A* on primary p. c. of tuner.

To Telegraph.

The two extra leads from transmitter arm must be connected to the two rear binding posts on the "Chopper" telegraph box (lettered *M*). Connect three cells of dry battery in series to the two left-hand binding posts (lettered *B*). Now throw the small switch arm on transmitter arm to its lowest contact.

By means of the small screw-driver adjust (when necessary) the

"chopper" contact in bottom of box (reached through the single hole in top of chopper box) until the hot-wire ammeter needle's throw is reduced to about one-half its normal reading when the telegraph key is held closed.

The Morse sending key may be operated at the highest possible speed. This chopper telegraph may be also used for calling purposes.

Remember always to throw the transmitter arm switch *up* for talking.

Care of Apparatus.

It is very important that all parts be kept clean and dry, especially when exposed to salt sea air and moisture. Keep doors of hood closed as much as possible, and all metal parts wiped dry, or with cloth dampened in "3 in 1" oil.

If moisture gets in telephone cords it tends to short circuit same, reducing the received signals.

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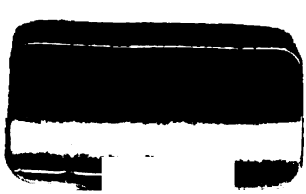

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